June 1956

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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

Self photograph of SPERT reactor during power surge . . . see page 44

Russian Thermonuclear Experiments ... page 36

Explanation of EBR-I Incident . . . page 35

G-E Engineers "Cook" Fuel Plates at 1000° F. in Special Test Loop

Testing atomic products before they're built is a good trick—if you can do it.

One way General Electric engineers do just this is with a special test loop designed to simulate reactor core thermal conditions. Fuel element materials and designs can be pre-tested in this loop for void distribution and steam slip, steam blanketing, and heat transfer characteristics—all while the reactor is still on the drawing board.

Proving critical calculations like these *in the design stage* is another example of General Electric engineering leadership in the field of atomic energy.

Atomic Power Equipment Department, General Electric Company, Schenectady 5, New York. 1961

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NUCLEONICS

JUNE • 1956

Vol. 14, No. 6

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About NUCLEONICS

Two years ago we published what we believe was the first report on work on controlled thermonuclear power (NU, June '54, p. 9). It was only a four-sentence item but its significance lay in the fact that it was the first indication AEC was doing any work in this area. Because until recently AEC would not admit publicly that it was even thinking about the subject, doing any kind of an accurate reporting job has been difficult, perhaps even more so than reporting on nuclear weapons. Even since the Geneva conference when the US, UK, and USSR owned up to having projects, technical information has been difficult to come by.

Thus the stage was set perfectly for the Soviet performance at Harwell on April 25. Whether it was for propaganda purposes or as an act of sincerity, the fusion talk by I. V. Kurchatov, a prominent Soviet nuclear figure, took the prize for stealing the march on the world in releasing information on this subject. Some key people in this country say they were merely trying to smoke us out and gave out no new information. Others feel it was a

NUCLEONICS

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About NUCLEONICS (Continued)

very significant talk that was given.

Whatever the case, anyone with any nuclear blood in his veins (and not necessarily only those with red cells) sought copies of the talk. Although the Russians distributed a number of copies at Harwell, these were gobbled up pretty quickly. We on NUCLEONICS immediately cabled our London office, and one of our men there got a look at the talk and cabled us a story, which was the basis for what appeared in our May issue. But then we realized that interest in the event was quite great and so we decided to publish the entire talk this month.

At that late date, getting a copy of the talk required some applied research. It turned out AEC had received copies from Britain but AEC felt they couldn't let us see it without an OK from the British. This prompted an inquiry to British officials who were visiting in this country. They weren't sure on what basis the Russians had given them copies of the talk, so they cabled home to find out. It was sort of like the friend of ours in one branch of the service who had a translation of a Soviet newspaper story on some nuclear project routed to him. The translation was stamped "confidential"!

We finally did get the copy that appears on p. 36 of this issue. As difficult as we knew it would be to get outsiders to comment on the talk, we went after them and got what we think is a very interesting set of reactions. These appear along with the talk.

•

In the air, on the land, and under the sea! It may be corny to put it this way but, as this is being written, various members of the NUCLEONICS staff are getting set to take off on field trips.

Perhaps the most unusual and exciting trip that one of us is taking is the one Managing Editor Jim Dutton is to get on the *Nautilus*. Fully equipped with ear plugs and boots, he's to sail out of the Hudson River, do some diving in the depths of the Atlantic and arrive the next day at New London, Conn. We don't see how Jim is going to be satisfied with land-based reactors any more. But reality being what it is, after he gets his land legs, he's to take off for Lynchburg, Va., to take a tour through the new Babcock and Wilcox fuel-element fabrication plant, and then on down to Wrightsville Beach, N. C., to sit in on part of International Nickel's annual shindig on corrosion.

Jim will be joined at Lynchburg by News Editor John Kenton, who will have come via Washington where he had two assignments: one to expose himself to a vacuum of words while digging in on a story on the aircraft nuclear propulsion program and the other shielding himself from the torrent expected to pour forth at the Congressional hearings on insurance.

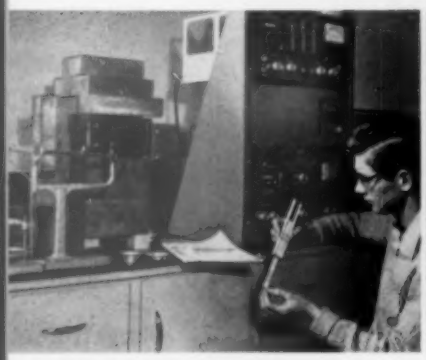
The man taking to the air is Editor Jerry Luntz, who is heading for Chicago where NUCLEONICS is co-sponsoring the Industrial Nuclear Technology Conference with the Armour Research Foundation.

To answer a question that may come to the minds of some readers, the magazine is put together at night!

—*The Editors*

LEADING SCIENTISTS CHOOSE NUCLEAR-CHICAGO INSTRUMENTS

. . . for accurate, dependable, radioactivity measurements



Uranium Ore Assay—Ontario, Canada.
Uranium ore producers use Nuclear-Chicago scaling units in assaying various ore samples to determine uranium content.

Medical Diagnosis—Detroit, Michigan.
Nuclear-Chicago Isotope Scanner makes it possible for physicians to have "picture" of radioisotope distribution in organs of patient.

Metabolic Research—Coconut Island, Hawaii.
Marine biologists use Nuclear-Chicago instruments for metabolic research, monitoring fish forced-fed radioactive strontium.

Petroleum Research—Pasadena, California.
Petroleum geologists determine radioactivity of oil well cuttings—use resultant "profile" to expand and develop oil fields.

Industrial Research—New York, N. Y.
Laboratory uses radioactive "dirt" and Nuclear-Chicago instruments to test washing machines, improve soil-removal techniques.

Diagnosis of Thyroid Function—La Crosse, Wis.
Nuclear-Chicago "Mediac" determines uptake of radioiodine by thyroid gland, helps physicians diagnose thyroid dysfunction.

Biological Chemistry—College Station, Texas.
Pea plants grown on a liquid radiosulfur diet and Nuclear-Chicago instruments help biochemists determine how plants produce amino acids.

Uranium Exploration—Wallace, Idaho.
Uranium prospectors use an ultra-sensitive Nuclear-Chicago airborne scintillation system to survey vast areas quickly.

Gamma-ray Spectrometry—Chicago, Illinois.
Radiation physicists study the energy spectrum of gamma emitting radioactive isotopes with Nuclear-Chicago spectrometer system.

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This reactor uses fuel elements of the long-burnup type. Spent fuel elements are stored in the service pool adjacent to the reactor until cool enough for futher handling.

The reactor and service pool can be equipped for neutron and gamma irradiation for research without interfering with reactor operation.

For more information, write for bulletin GER-1220, Sect. 192-7, or contact the Atomic Power Equipment Dept., General Electric Co., Schenectady 5, N. Y.

**Boiling Water Reactor*

Progress Is Our Most Important Product

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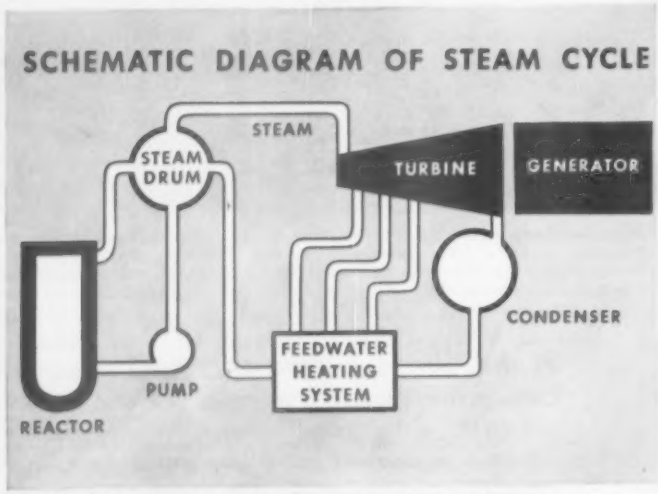
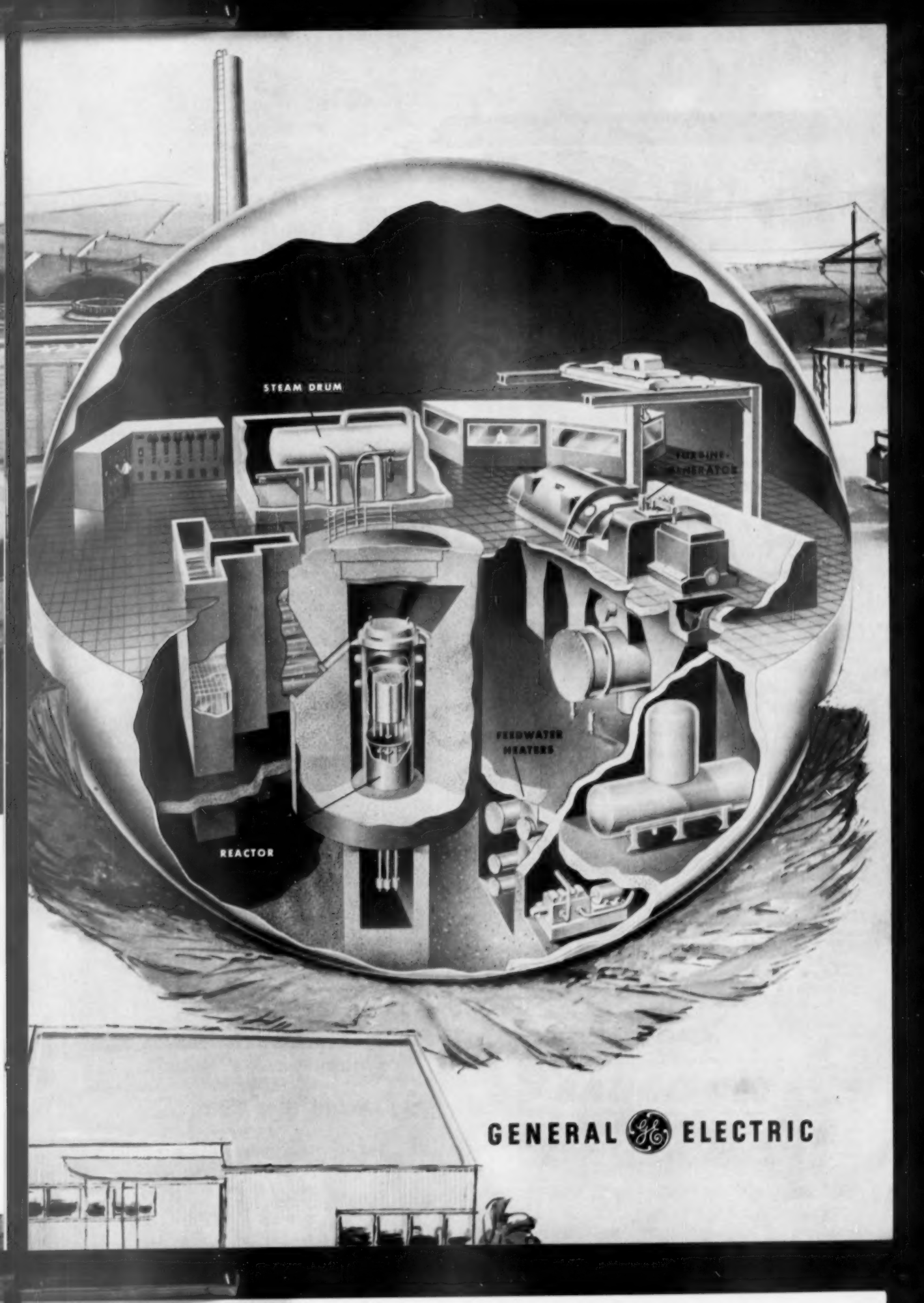
SIMULATED FUEL ELEMENT being installed in a heat transfer loop for tests under reactor thermal conditions. This is one of G.E.'s supporting atomic development programs to advance reactor design.

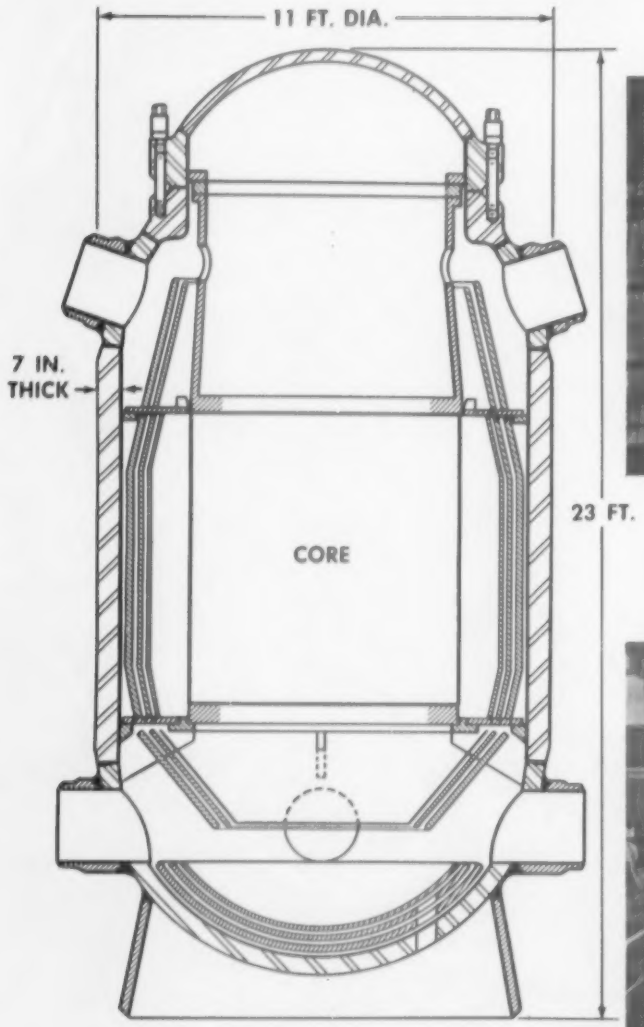


STEAM FLOWS FROM REACTOR to drum. Saturated steam passes to turbine; water goes to feedwater heaters and returns to steam drum. Forced circulation pump provides automatic control of response to load changes.

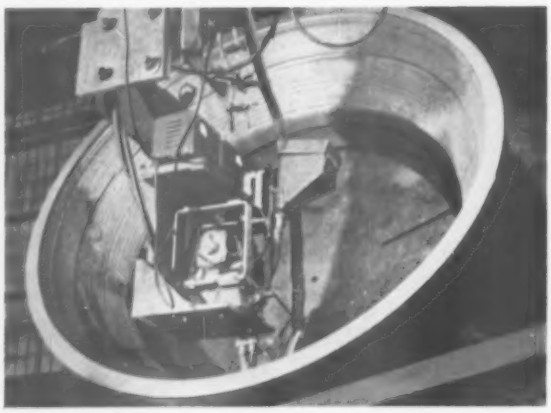

STEAM DRUM
FEEDWATER HEATERS
REACTOR
GENERAL ELECTRIC

B&W AND ATOMIC ENERGY 2

B&W Pressure Vessels



REACTOR VESSEL



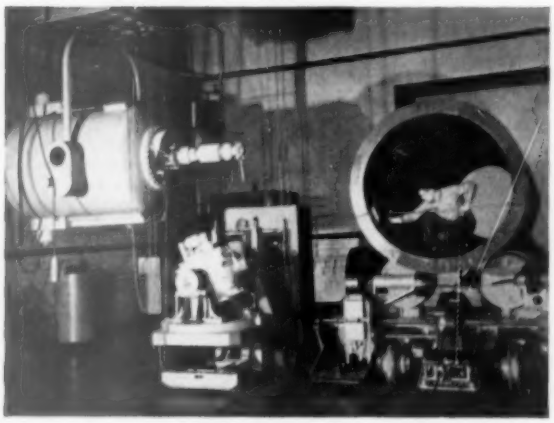
"B&W Clad" is a patented, electric-resistance welding process designed and developed by B&W engineers specifically to weld stationary-clamped base plate and alloy sheets.

This 8500-ton capacity hydraulic press bends and forms steel plate often over seven inches thick for pressure vessels.

For Nuclear Reactors

• Resist Corrosion • Withstand Thermal Stresses • Provide Absolute Leak-Tightness

Starting the automatic electric welding operation that follows heavy press forming and machine-grooving of edges, to weld the pressure vessel sections into an integral structure. Bottom section, various nozzles and attachments, lid or closure, are last to be attached.



Gamma ray sources have been used by B&W for radiographic examinations of weld seams in pressure vessels since 1947. X-ray examinations, by machines of up to 2-million volt strength, are also used.

Unqualified structural soundness throughout is the basic requirement for pressure vessels in nuclear service — a requirement that B&W pressure vessels have been meeting since long before nuclear energy became a power source.

Design, engineering and manufacturing methods for B&W pressure vessels, long proved in service, assure absolute control over corrosion, thermal stresses and leaks.

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AE-22

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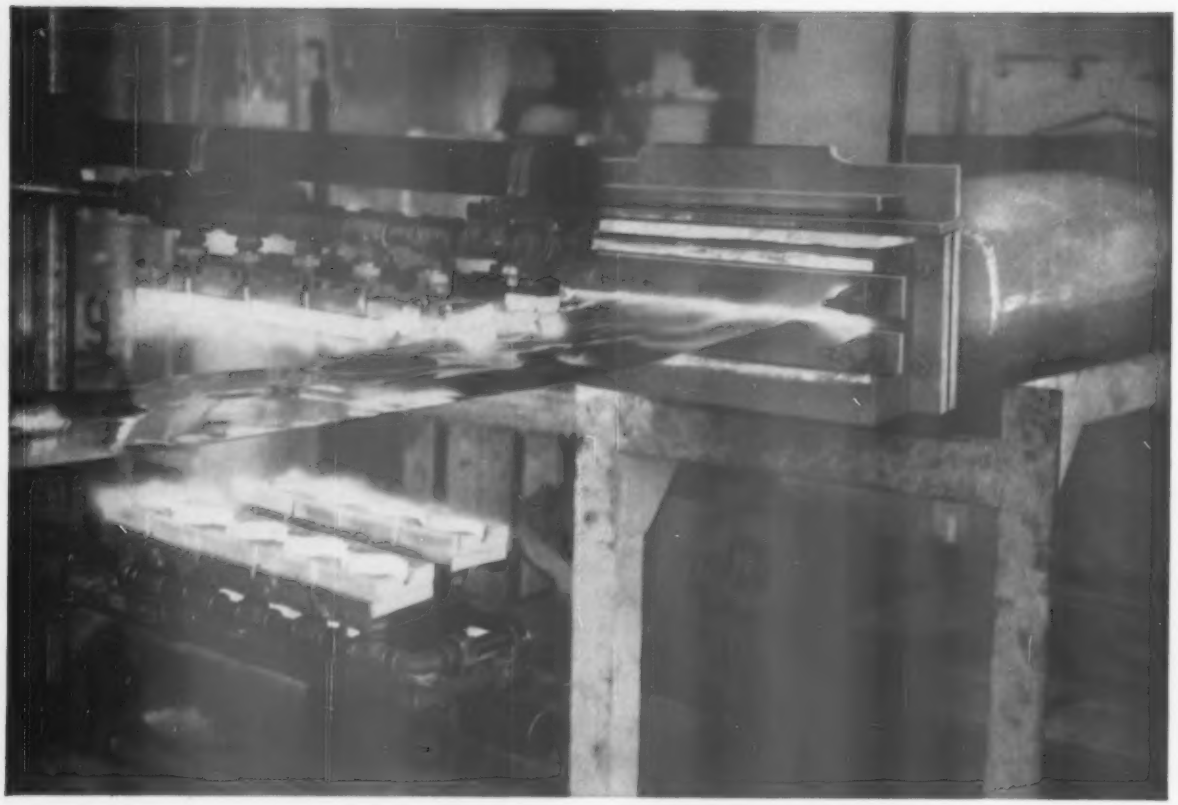

Inconel offsets thermal and corrosive attack on furnace muffles for strip annealing operated at temperatures up to 2200°F.

Alloy takes 2200°F in stride ...corrosion, too

It's hard to find a metal that takes heat and corrosion as well as Inconel.

Consider this annealing furnace muffle. It operates at temperatures up to 2200°F . . . superhot combustion gases outside, carbon and hydrogen inside. In this inferno every metal tried cracked in weeks.

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Inconel is proving of special value in the handling of atomic energy problems for three reasons.

Inconel is structurally stable. It is not subject to embrittlement on prolonged heating.

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Inconel is easy-to-work . . . easy to form, machine, weld...available in all commercial wrought forms.

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For an immediate high temperature problem, call in Inco's Technical Service Section... giving full details, if possible. Write:

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Accessories to increase the 24-210's convenience and usefulness include: Sampling Probe (right) for pinpointing leaks in pressurized systems; Audio Alarm (above right) which provides audible signal whose pitch varies with the size of the leak; Mobile Workstand (extreme right) which carries instrument, provides work table, drawer facility, and lower shelf for mounting auxiliary vacuum system.

Send today for a complete description of CEC's new 24-210 Leak Detector. Ask for Bulletin CEC 1830-X5

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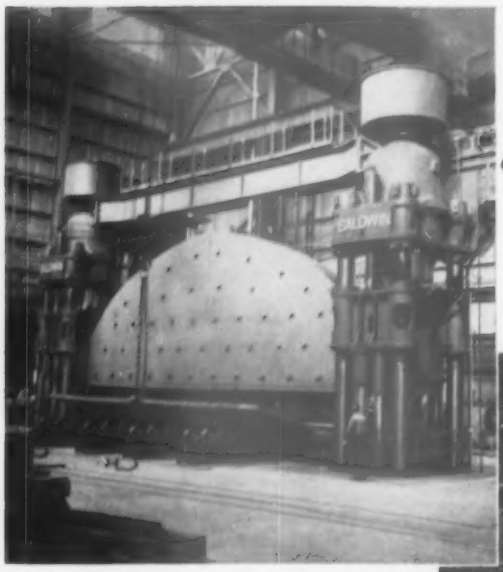

This huge, 8000-ton hydraulic beam press easily performs bending and forming operations on steel plates up to 9 inches thick and 39 feet in length.

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The nuclear program is now expanding. Men are needed with training or experience in almost all fields of science and engineering to investigate the feasibility of nuclear powered aircraft.

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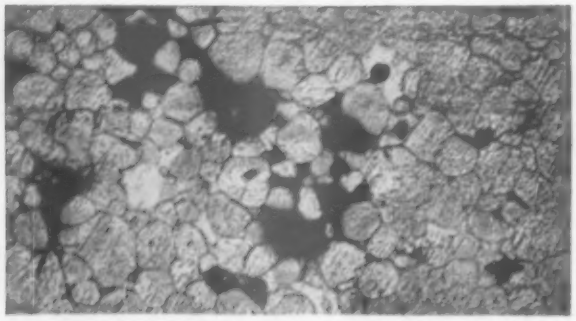
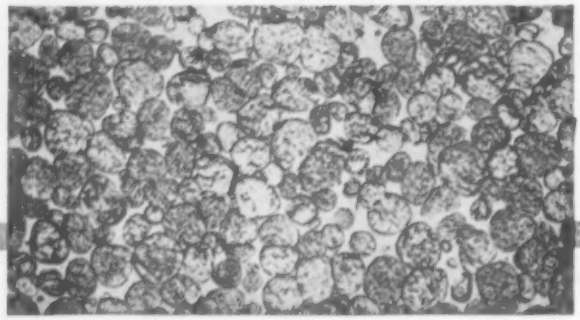
MALLORY

Under the microscope, ordinary shielding metals (above) reveal voids that seriously reduce radiation absorption . . . while Mallory 1000 Metal (below) shows high density, positive shielding all the way through.





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LATE NEWS and Commentary

Gore Bill Debate

The United States' peacetime nuclear power program came in for some searching scrutiny last month. It was prompted by hearings before the Joint Committee on Atomic Energy on the bill proposed by Sen. Albert Gore (D-Tenn.) that calls for the construction of six power reactors by the Government.

The hearings raised, and attempted to answer, these questions:

1. What is the true nature of world leadership in nuclear power and of America's role in it? Does it consist primarily in developing the technology to provide the basis for eventual construction of prototype reactors and commercial power plants? Or does it consist of building such plants on an accelerated scale to obtain experience and achieve kilowatt production goals?

2. Is it important for America to maintain her world leadership in civilian nuclear power development?

3. If so, how does America maintain this leadership? Should it do so through the private demonstration program, through construction of Government reactors, or through a combination of the two?

Committee chairman Sen. Clinton P. Anderson (D-N. M.) said the nub of the problem seemed to be the pace of nuclear power development. This being so, who should determine the pace, and whose task is it to keep the program moving? Other questions to be determined, said Anderson, are:

1. What are the technical roadblocks in civilian nuclear development?

2. Does it appear that the private nuclear power groups will achieve their schedules for prototype development set for 1960–62?

3. If Congress authorizes six or even three reactors for construction, which types should be built, and where?

"I believe," said Anderson, "we should be particularly interested in atomic power plants which will serve the emerging needs of the friendly countries of the West, as well as in achieving economic atom power in this country."

Gore maintained that our present program is inadequate; that this program is being delayed by "roadbocks"; that this country is losing the atomic power race to the Soviet Union and Britain. He argued that "we need kilowatt capacity because we need to have reactors in operation." And, he says, the Government should build these reactors.

The Bill's Provisions

Gore's bill calls for six reactors to "demonstrate the practical value of utilization facilities for industrial or commercial purposes." Each should be of a "different design, each design being selected on the basis of a determination that the construction of a facility so designed gives promise of making a significant contribution to the advance of the science and technology of the commercial and industrial aspects of the atomic energy program." Finally, he wants the reactors in different geographical sections, chosen because of their "need for additional electric generating capacity."

Gore—and he is supported by such committee members as Sen. Jackson (D-Wash.) and Rep. Chet Holifield (D-Calif.)—maintains there are not enough types of reactors being proposed. He pointed to the homogeneous, the Hanford graphite, the Savannah River heavy water, and the British gas-cooled reactors as types that are not being pursued toward full-scale projects.

Gore's position received some backing from Walter Zinn, retiring head of Argonne National Laboratory and special consultant to the Joint Committee for these hearings. Zinn said that this country's choices of reactors for full-scale construction "are as good a bet as any." But he believes there are other possibilities, too:

Zinn's Picks

1. The Hanford reactor "can be converted by pressurizing the water-cooled channels. This may be an economical type for power."

2. If the Savannah type of reactor were changed to a PWR, it "gives as much promise as any heterogeneous type we have now."

3. "There are several versions of the heavy-water reactors we might be pursuing."

4. The aqueous homogeneous type is "very attractive" but "we lack large-scale experience" and it might be wise to undertake a large-scale prototype.

5. Another type that has been bypassed is the gas-cooled. This type "inherently carries the promise" of getting away from the steam cycle and going to a gas cycle.

6. There is now only one version of the sodium-graphite type and it might be wise to consider other versions.

Less specific in his position was Henry DeWolf Smyth, chairman of the Board of Scientific and Engineering Research, Princeton University. He called for a "vigorous and varied program of reactor development in this country," but also noted that "there is room for a difference of judgment among reasonable men" as to the proper course to pursue.

Smyth also believed it would be "unwise" for Congress to order the AEC to build power plants of a particular size and type. And, he said, Congress "should make it clear what it considers the appropriate rate of progress." Smyth proposed greater AEC emphasis on relatively small power-producing reactors for actual use.

On the other side of the ledger were witnesses who maintained that the U. S. is leading in nuclear power development, will maintain its leadership; and that there is no need for the Government to build additional reactors.

AEC is Against

The AEC is dead set against the Gore bill. Its position was perhaps best put by Commissioner W. F. Libby, then acting chairman, in a letter to Senator Anderson in mid-May. Wrote Libby:

"It has been, and is, the Commission's view that the goal of United States policy should be the eventual development of economic nuclear electric power and not an immediate 'kilowatt race' with other nations. It should be clearly emphasized that it is our belief that an aggressive and continuing reactor research and development program is the only basis on which we can establish and maintain world leadership in the development of nuclear power and achieve our goal of economically competitive nuclear power in the United States. To prevail in a 'nuclear kilowatt race' might, in the short-run, appear to be an accomplishment, but we fear it would not only be unduly costly in terms of the benefits to be gained, but would divert effort and scarce technical manpower from the real goal and consequently delay its achievement. The attainment of competitive nuclear power in the United States, with its efficient conventional power plants and relatively cheap fuels, is going to be difficult. We cannot favor a measure which sets an arbitrary goal in terms of the number of nuclear power facilities without providing the flexibility to take into consideration the competing, and in our view, paramount demands of research and development.

Industry First

"It is our belief that publicly, cooperatively, and privately owned utilities engaged in the sale of atomic energy and equipment manufacturers are in a much better position than the Commission or its laboratories to assess the economics of particular reactor concepts and to determine which ones are in the stage of development where the construction of a prototype is a logical and appropriate step. For these reasons the Commission has encouraged industry to undertake the construction and operation of full-scale prototypes. However, if a particular reactor concept appears to us to have reached the stage of development where the construction of a prototype is a logical and appropriate step, and if it should appear, after appropriate public invitations for proposals for joint AEC-industry projects, that industry is not prepared to undertake the construction and operation of such a prototype, the Commission would give serious consideration to the desirability of going forward with the project using entirely public funds

"We believe it to be of the greatest importance that the maximum economic incentives to cost reduction be preserved at this stage. This, in our opinion, can

(*Continued on p. 20A*)

ROUNDUP

Russian Nuclear Progress Reported on Many Fronts

(With interest in Russian nuclear activities running high, NUCLEONICS *has here assembled reports from various sources on different aspects of work in this field in the Soviet Union.)*

Seven Swedish nuclear scientists were recently invited by the USSR Academy of Sciences to visit Russia for 10 days and see laboratories and installations there. One of them, N. G. Sjöstrand, of the physics department of the semipublic Atomic Energy Corp., prepared these notes for NUCLEONICS on his return:

"The Moscow Institute of Physics has an enriched uranium-graphite reactor with a power of 10 Mw and a maximum neutron flux of 8×10^{13} [NU, Sept. '55, p. 53]. The reactor has five loops for testing fuel elements, and is used for many nuclear physics experiments. Close to the reactor building is a hot laboratory devoted to chemical and metallurgical work. Several cells equipped with master-slaves were demonstrated. At the physics department we saw electromagnetic isotope separators capable of producing gram quantities per day. A new principle for building high-energy accelerators was described, and experiments on these lines were in progress.

"At the Thermal Electrical Laboratory we saw the heavy-water reactor, which is now under reconstruction. It will be charged with enriched uranium and is expected to give a neutron flux of 2×10^{13}. A 14-Mev cyclotron at this laboratory is mainly used as a neutron source for time-of-flight measurements of cross sections.

"The Lebedev Institute has no reactor, but neutron experiments are carried out with two Cockcroft-Walton accelerators. Moreover there is a 280-Mev electron synchrotron, and departments for microwave spectroscopy, cosmic rays and electronics, among other things.

"At Moscow University we spent most time at the physics faculty, which has about 2,500 students.

"One day was devoted to a trip to the atomic power station outside Moscow. As is generally known, it has an electric output of about 5 Mw. We learned that besides producing power, the reactor is much used for production of radioactive isotopes and as a tool for physical investigations [NU, Sept. '55, p. 40].

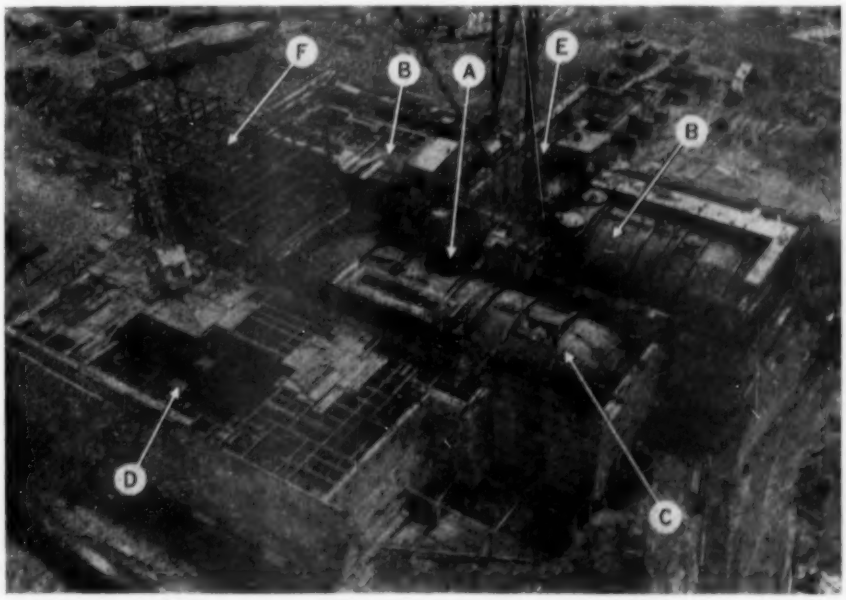
"Another trip was made to the Institute for Nuclear Problems, which is situated close to where the canal from Moscow joins the Volga. The 660-Mev synchrocyclotron there is mainly used for production of mesons and exploration of their interactions with other particles. The 10-Bev synchrotron is also located here. It has a diameter of about 60 meters, and will start operation within a year. It was said that these two accelerators will form a part of a joint laboratory of the eastern countries [NU, May '56, p. 23] corresponding to the Western European CERN in Geneva. It is also planned to build a cyclotron for acceleration of heavy ions and a research reactor with a neutron flux exceeding 10^{13}.

"On our way home from Moscow we spent one day in Leningrad, where we had a look at the Radium Institute and at the Leningrad Institute of Physical Technology which, among many other things, has a 10-Mev cyclotron and a 100-Mev electron synchrotron."

• • •

From Vienna comes this report on the nuclear Arctic icebreaker the Soviet is planning:

The first nuclear-powered icebreaker was ordered under the sixth Five-Year plan, i.e., in the period 1956–60. Only half the output of its 200-Mw (heat) reactor will go to power the ship's engines; the other half will be used to produce steam for the two squirt-lines that will melt ice ahead of the vessel. All superstructure installations on the 25,000 gross ton funnel-less ship will be streamlined. A helicopter will be stored under a glass dome on the afterdeck. The ship will be 525 ft long, 82 ft in beam, and subdivided into 11 independent water-



LAST MONTH PWR, nation's first full-scale nuclear power plant, was really taking shape. Photo shows future location of reactor at *A*, at lower end of fuel handling canal *E* and behind vapor container for auxiliary equipment *C*. To either side are two vapor containers *B* that will house two heat exchangers each. At *D* is being erected the platform on which will be located the turbine-generator set (on same level as crane in photo). At *F* is rising steel skeleton of office and laboratory building. Vapor containers are of 1-in. steel plate, 50 ft in diameter; auxiliary container is 150 ft long. Heat exchangers and auxiliary components will start arriving on site this summer

tight compartments. Double keel and double hull will provide protection even in drifting ice.

The powerplant is located forward, with the reactor placed in a specially isolated section. Steam lines reach two sets of turbines and generators, each of which drives two screws (there are four screws in all: two forward and two aft). The generators have a total peak yield of 60 Mw; of this 40 Mw is used to drive the 40,000-hp engines, and 20 Mw are available for the main centrifugal pump for the ice-melting tubes, for steering, and for all heating, lighting, cooking, elevators, and other services.

Remote control has been pushed to an advanced stage: from reactor control to the navigating of the ship, all possible operations are remotely controlled from a main switchboard directly under the bridge.

The ice-melting mechanism consists of a heavy centrifugal pump from which steam is blasted through twin pipes at the forepeak at "several hundred atm, using ten-thousands of metric tons of water;" even year-old polar ice is expected to give way to this powerful heat attack.

Four compartments of the vessel are given over for passengers and 5,000 tons of freight. Drinking water, stored between the hull's double walls, will, it is planned, counteract the rolling of the ship.

About 78 kg of fuel will run the ship for one year, as compared to about 150,000 metric tons of diesel fuel for an equivalent conventional vessel.

• • •

The Academy of Sciences began publication last month of a bimonthly journal, *Atomnaya Energiia*. I. I. Novikov is editor-in-chief, N. A. Vlasov is his deputy, and a nine-man editorial committee includes A. I. Alikhanov, V. I. Veksler, and others whose names are familiar in this country.

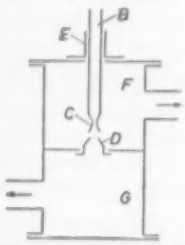
The May-June issue contains a lead editorial and statement of purpose entitled "Atomic Energy—to Serve the World" in which it is said, "The magazine will print original and survey articles by Soviet and foreign authors, devoted to atomic physics, atomic power, atomic raw materials, application of radioactive isotopes, atomic safety engineering and other problems. The editors of 'Atomic Energy' invite scientists and engineers engaged in peaceful utilization of atomic energy, both in the USSR and abroad, to submit the results of their investigations for publication . . . "

The issue, of 128 pp., includes three reactor papers (on a heavy-water gas-cooled power reactor, by Alikhanov, Vladimirskii, and others; and two papers on the 5-Mw power reactor by Blokhintsev—who described it at Geneva—and others). One paper is on metallurgy (iodide method of Zr refining); three are in physics (energy levels of Pu^{239} and Pu^{239} nuclei, time-of-flight measurements of fast neutrons, and principles of acceleration of charged particles, by Veksler); one on methods of prospecting for uranium, and one on isotopes and investigation of pathogenesis of metabolism diseases.

Finally, there is a section on news of science, an article on the recent conference on the physics of nuclear fission, a piece on a Russian exhibit on peaceful uses of nuclear energy, a bibliography of some 100 titles published in the field in 1955–56, and a section on foreign science and engineering.

New Isotope Separation Process Pushed in Germany

Considerable interest has been aroused by German experiments to achieve U^{235} separation by a cheaper and simpler method than gaseous diffusion (NU, Feb. '56, p. 15). In response to a NUCLEONICS inquiry, Prof. E. W. Becker of the Physics Institute at the University of Marburg, who is conducting the work, reports as follows: During recent experiments, still with argon and xenon, the counterpressures were considerably increased and the expansion ratio lowered. However until now only pressures below 100 mm Hg have been used. The separation factor for each unit lies in the same order of magnitude as for a diffusion barrier. Experiments with uranium hexafluoride are to begin shortly; extrapolation of the results obtained with noble gases hold great promise.



An account of the basic principles of the Marburg process may be found in a paper, "Die Trenndüse" (The Separation Nozzle) by Becker, Bier, and Burghoff in *Zeitschrift für Naturforschung*, Tübingen, Vol. 10a, No. 7, 1955.

The adjoining diagram shows the arrangement of the apparatus. A gas feed-pipe *B* carries at its lower end a DeLaval nozzle *C*, opposite which is a cone-shaped paring tube *D*. The gap between the two can be remotely controlled by raising or lowering *B* by means of the gastight sleeve *E*. The lighter component gas tends to accumulate near the edges of the stream issuing from the nozzle, is pared off by the separator *D*, and is collected in the chamber *F*; the heavier component tends to collect at the center of the stream, therefore passes through the central hole in *D* to the chamber *G*. The outlets of *F* and *G* are attached through valves to mercury pumps (Hg 45 Leybold), backed up by rotary pumps. The gas samples are drawn off on the forevacuum side of the mercury pumps at 12 mm Hg maximum.

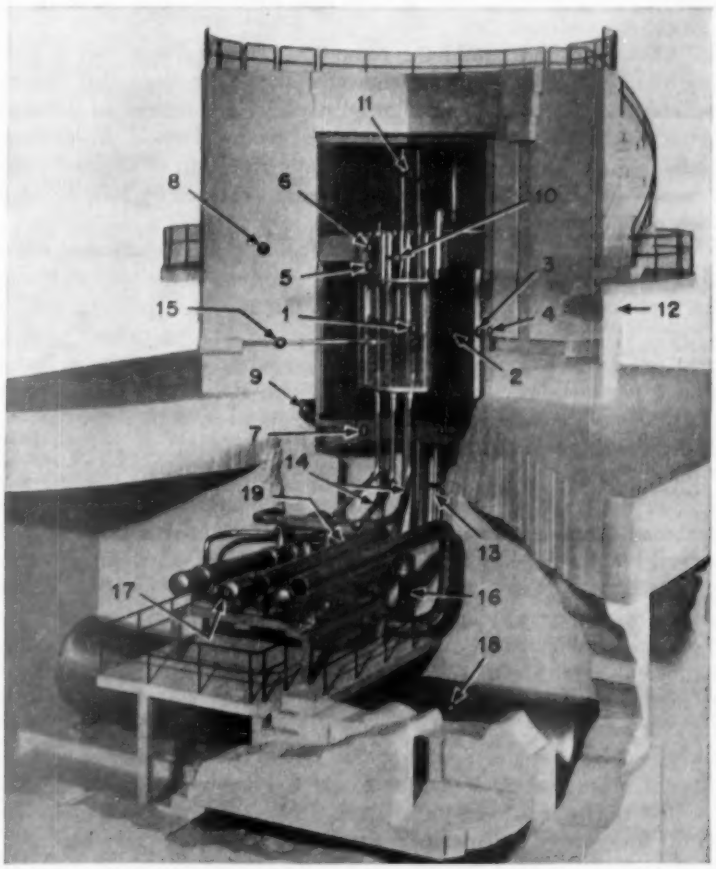
Becker and his team have already done considerable work on the effect on the separation factor of the diameter of the aperture in the separator and of its distance from the nozzle. They have found that the capacity of the apparatus can be considerably increased without loss in effectiveness by using flattened rather than round nozzles and separators. In particular a 0.2-mm-wide 20-mm-long nozzle gave separations like those obtained with a 0.5-mm-diameter round nozzle and yet had 12× greater throughput. Further increase in throughput was limited only by available pumping capacity. Becker contemplates use of his apparatus in cascades, with the depleted gas being cycled backward.

He says that although the separation factor in his process is comparable to that in gaseous diffusion, replacing barriers by separation nozzles leads to a considerably greater reliability of operation, and makes possible substantially higher output for equal expenditure on separation equipment.

Construction Begun on First Swiss-Built Reactor

After several years of studies, hesitations, and theoretical controversy, the first Swiss-made reactor is taking shape. Earthwork is now completed on the forest-surrounded site along the river Aare at Würenlingen, 30 mi west of Zürich; concrete foundations are nearing completion. Some components have already been ordered from various Swiss firms, prominently including Brown Boveri & Co. of Baden, Escher Wyss & Co. of Zürich, and Sulzer Bros. S.A. of Winterthur.

These three firms, the country's largest in the mechanical engineering field, are prime movers of the project, having set up a joint study group back in 1951 to explore the practical possibilities of nuclear power for Switzerland. Starting with no government aid at all, but with the support of the Zürich Polytechnic's Prof. Paul Scherrer (Swiss nuclear research pioneer and now head of her AEC), the group made a number of design studies.



MODEL OF SWISS P-34 REACTOR shows: 1, natural U–D_2O core; 2, graphite reflector; 3, boron shield; 4, steel cylinder; 5, water shield; 6, steel cover; 7, steel floor; 8, concrete shield; 9, ventilation channel; 10, uranium rod; 11, cadmium regulating rod; 12, (behind concrete shield) control motors; 13, vertical irradiation channels; 14, high-temperature test circuit; 15, horizontal irradiation channel; 16, D_2O pump; 17, cooler; 18, D_2O reservoir; 19, coolant water pipes. P-34 will operate at 10 Mw heat, using D_2O as moderator and coolant. An unusual feature is vertical channels in which temperature levels independent of, and higher than, those of core itself will be maintained; they will serve to test fuel elements and coolants intended for power reactors operating at higher temperatures than P-34. Design is so planned that "trouble" in one of channels will not seriously influence operation of reactor

By 1955 official help was forthcoming, and a special nonprofit corporation, "Reactor, Inc.," [Réacteur S.A.] was set up in March 1955. Shareholders are 125 private firms interested in the development of nuclear energy; 49% are industrial firms, 31% electric utilities, and 20% banks, insurance, and investment firms. The present paid-in capitalization is about $372,000, but another $3.34-million is pledged. And under agreements with the government, Berne will pay the group $1.144-million toward construction, up to $412,000 for testing purposes before regular operation starts, and $229,000 a year for at least five years toward operating expenses. The government will own the plant; Reactor, Inc., will build and operate it.

The Swiss reactor, designated P-34 (for Project 34, because it is the 34th design study Reactor, Inc., has made since the firm was founded), is not to be confused with Switzerland's other pile—the Oak-Ridge-built Geneva exhibition reactor. That small swimming-pool reactor, shown at last fall's Atoms-for-Peace conference and then sold to Switzerland, is now also to be set up permanently at Würenlingen.

Two "working communities" are doing the preparatory work on P-34: a nuclear physics group staffed by physicists from Brown Boveri, Escher Wyss, and Sulzer, and an engineering group drawn from two electrical holding companies, Electro-Watt S.A. of Zürich and Motor-Columbus S.A., Baden. In its first annual report, just published, Reactor Inc. says all technical problems have been solved.

P-34 will serve for materials testing, physics and engineering research on industrial and power reactors, isotope production and nuclear training.

Some Swiss physicists feel the design—established in April 1955 when enriched U was scarce—was made obsolete by the U. S. offer this February. However, work continues—mainly to permit further experimentation and training in preparation for a Swiss-built power reactor. With waterpower resources scheduled to be fully tapped by 1975, this is becoming urgent. Reactor Inc. has already started studies for a power reactor to be built soon, probably also at Würenlingen, to run on enriched U.

(*Continued from page 18A*)

best be accomplished by industry taking financial and technical responsibility under conditions where it will sustain the major burden of whatever loss occurs and accrue the advantage of any economies. Government assistance in some respects may be necessary, but we do not believe that government responsibility or government cost contracts are likely to sufficiently provide the desirable incentives to cost reduction.

Industry Responding

"In our opinion American industry is responding to this challenge in a very encouraging manner. It cannot be overlooked that we have had a formal power reactor development program for only slightly more than two years and that this length of time is wholly insufficient for the development of the vast technology necessary for construction and operation of really economic power reactors of any size or type."

Furthermore, Libby said AEC could not meet the demands on manpower that additional Government reactor projects would pose, and that problems of site selection and disposition of power would catapult AEC into "the crossfire of the public versus private power controversy." Finally, he said, development, design, construction, and operation for five years of the Gore-bill reactor plants would cost $600-million over a ten-year period (not including cost of auxiliary facilities for transmission, fuel processing, etc.—at least four times the value of the power produced.

And AEC Chairman Strauss told the committee: "Our present goal is more scientific knowledge, not simply more kilowatts . . . We believe that the enforced adoption of arbitrary goals of kilowatt capacity or numbers of full-scale reactors for an early date, such as 1960, is unwise because it would divert scarce technical skills from activities which promise greater results in subsequent years. The mere numbers of kilowatts of capacity to be in existence by 1960 is not in our view, very meaningful."

McKinney Neutral

Probably most neutral of the witnesses to testify was Robert McKinney, editor and publisher of the Santa Fe *New Mexican*, and chairman of the recent citizens' panel which reported to the Joint Committee on the impact of peaceful uses of atomic energy. He argued against the construction of government nuclear power plants "just for us to look at, brag about, and subsidize," and for an "international atomic power demonstration program" with this country building reactors abroad. Such a course, said McKinney, could serve as the "keystone for a new and effective structure of international policy" for the U. S.

But he also maintained that the present U. S. program of reactor development was deficient in the small and medium-sized types. A 10-Mw nuclear power plant built abroad, he said, can go further in capturing the imagination of people around the world than a 100-Mw conventional plant costing many times more.

Industry objections to the Gore proposal stressed the technical manpower situation. Such witnesses as Philip Sporn, president of American Gas & Electric; Charles E. Oakes, president of Pennsylvania Power & Light; Francis McCune, vice president of General Electric; Walker L. Cisler, president of Detroit Edison, and others contended that adoption of the Gore proposal would place a great strain on existing manpower.

'Wasteful Drain'

Sporn told the committee the Gore proposal "would mean a wasteful drain on engineering and other technical personnel which I know we cannot afford." Oakes presented the committee with a number of copies of statements, news articles, figures, and quotes to illustrate the technical manpower shortage.

While the supporters of the Gore bill—and they included spokesmen for labor, electric cooperatives, and public power groups—tended to look upon the yardstick as one of more kilowatts, opponents were more concerned with technological progress.

Sporn, who with Cisler was a delegate to the Geneva Atoms-for-Peace Conference, noted that in the U. S. economy "those concepts and designs which show promise for advance in efficiency or economy tend to be selected quickly as they become ready for development. There is every reason to believe that this process is working and will continue to work in the atomic power field."

Congress May Vote Federal Reactor Risk Insurance

Congress appears ready to underwrite most of the insurance risks that now cast a shadow on development of a private nuclear power generating industry in the United States.

This is the major conclusion to be drawn from a week of intense hearings on reactor disaster indemnification by the Joint Congressional Committee on Atomic Energy.

Sen. Clinton P. Anderson (Dem.-N. M.), JCAE chairman, who has been somewhat impatient with the pace at which industry has been going ahead on building power reactors and who called the hearings to clear "other possible roadblocks" as well as the vexing insurance problem, expects fairly easy sailing for legislation providing Government indemnification. However, one basic difference in philosophy came to light between AEC, which submitted a proposed legislative draft, and Senator Anderson, who criticized it and who has since filed a bill of his own.

The difference arose when—after AEC had presented its proposal calling for the Government to assume liability for any accident damage above the $65-million covered by the private insurance industry—Anderson charged that the AEC had been concerned only for the interests of stockholders of big companies, not for the public at large. The AEC draft does not *require* licensees to take out the maximum available private coverage; consequently, Anderson asked, if a small outfit such as a cooperative or a college with a research reactor could afford to pay private insurance premiums only for, say, $5-million worth of coverage, who would be liable for public claims in the range between $5-million (where private coverage stopped) and $65-million (where Government liability began)? AEC had no answer, said this would be uncovered. "We have not yet decided," said Civilian Application chief Harold Price, "on what should be the Commission's attitude with respect to how much resources in addition to that [ability to pay AEC for fissionable material used, lost and burned up, and financial ability to carry forward the project] the company should show for the purpose of meeting the claims of third parties against damages from accidents."

Rep Sterling Cole (Rep., N. Y.) declared, "I cannot conceive that the Commission would be justified in granting a license unless the Commission was satisfied that the public interest was protected, either by way of adequate insurance or by way of assets the applicant may have. Why is it not a policy of the Commission to say so?"

"I think the Commission will go ahead and adopt a policy on the questions you have raised," Price replied. "At the moment it is no problem because the companies are talking about wanting resources way above any figure that I would think

AEC Retracts on Fusion Information for Industry

An examination by NUCLEONICS of AEC open files on its access permit program showed that as of mid-May, 35 companies had been granted access to secret information on controlled thermonuclear reactions. They are:

Aerojet-General Corp., Azusa, Calif.
Allis-Chalmers Mfg. Co., Milwaukee
American Gas & Electric Service Corp., New York
Babcock & Wilcox Co., New York
Baltimore Gas and Electric Co., Baltimore
Central Illinois Light Co., Peoria, Ill.
Cincinnati Gas and Electric Co., Cincinnati
Cleveland Electric Illuminating Co., Cleveland
Commonwealth Edison Co., Chicago
Consolidated Edison Co., New York
General Dynamics Corp., New York
General Electric Co., Schenectady
General Public Utilities Corp., New York
Illinois Power Co., Decatur, Ill.
International Tel. & Tel. Co., New York
Jackson & Moreland, Boston
Jersey Central Power and Light Co., Asbury Park, N. J.
Kansas City Power & Light Co., Kansas City, Mo.
Walter Kidde Nuclear Laboratories, Inc., Garden City, N. Y.
Arthur D. Little, Inc., Cambridge, Mass.
Metropolitan Edison Co., Reading, Pa.
North American Aviation, Inc., Downey, Calif.
Nuclear Power Group, Inc., Chicago
Pennsylvania Electric Co., Johnstown, Pa.
Precision Technology, Inc., Livermore, Calif.
Public Service Electric & Gas Co., Newark, N. J.
Ramo-Wooldridge Corp., Los Angeles
Raytheon Mfg. Co., Waltham, Mass.
Robertshaw-Fulton Controls, Anaheim, Calif.
Stanford Research Institute, Palo Alto, Calif.
Technical Research Group, New York
M. Ten Bosch, Inc., Pleasantville, N. Y.
Tennessee Valley Authority, Chattanooga, Tenn.
Union Electric Co. of Missouri, St. Louis, Mo.
Washington Water Power Co., Spokane, Wash.

One curious thing that strikes the eye about this list—considering that AEC's original fusion access announcement was in the form of an invitation to industry to participate in the program—is that more than half—19 of 35—are utilities that presumably would have more to learn than to contribute to the controlled fusion program, and that a number of companies that would be in a position to contribute are notable by their absence.

Late last month the word was out: AEC had put the lid back on controlled fusion, "pending further review." Project Sherwood people were said to be somewhat embarrassed at what appear to have been orders from above, since it was AEC that had publicly invited industry in, then changed its mind. Originally, in announcing on Feb. 3 that access would be granted, AEC had declared: "The availability of such information under the access permit program will, it is hoped, permit much wider independent experimentation and research, encourage more people to work in the field, and lead perhaps to earlier solution of some of the enormously difficult problems involved." It was said that only some of the very biggest manufacturers were to get actual access to fusion information, on their insistence that they be allowed to watch what happens while they invest millions in fission.

Meanwhile the British Atomic Energy Authority invited scientists from industrial research concerns to a fusion information meeting, said it would share its thermonuclear secrets with private industry in the drive to harness fusion for peaceful purposes.

the Commission would impose as a minimum. They are saying that even $65-million is not enough."

This does not apply to small organizations, Anderson objected, pointing out that the Nebraska Consumers Public Power District had been unable "to get a firm commitment from anybody to carry their insurance thus far." "If we are going to try to run the program for Consolidated Edison and Commonwealth Edison and Detroit Edison to build plants and do not want to get small plants in it, then, of course, you are operating on the right theory," Anderson told Price. "If you are talking about keeping them out, this would keep them effectively out. You say, 'I am sorry, but you are a small REA. You join up with the Consolidated Edison or Commonwealth Edison or Detroit Edison and we will talk to you.'"

Concluded Anderson: "I think maybe you had better take a look at the possibility of requiring them [operators] to carry something to protect the general public."

Another point at issue: AEC and industry witnesses asked that the Government's excess liability have no ceiling placed on it. "If industry is not satisfied with half a billion, it may end up with nothing at all," Anderson remarked; "you can't pass a blank check through Congress . . . In suggesting $500-million, I was trying to see if we could not get some figure that would not frighten the country or the Congress to death and still solve the problem which the producers of parts face and which the fabricator of the entire reactor faces, and which the operator of the reactor would eventually face once he puts it into operation."

Earlier, Commissioner W. F. Libby, testifying on the maximum possible effects of a reactor failure, had put the range of worst possible property damage for a 10-Mw plant at $5–24-million, for a 100-Mw reactor at $50–200-million, in case of core rupture and complete release of all fission products accumulated after 100 days' full-power operation. He added, however, that "the probability of a major reactor failure is vanishingly small, and that the essential integrity of containment structure can probably be assured by conventional engineering design and construction. Looking at it pessimistically we might expect a release of 1% of the fission products in the event of a reactor failure; for a 100-Mw reactor such a failure would be equivalent to total release from a 1-Mw reactor. Such a release could result in damages of the order of only a few million dollars, well within the range of experience in conventional industries."

One week after close of the hearings, Senator Anderson introduced his bill (S.3929) setting up a Federal reactor hazard insurance program, but without the shortcomings he had criticized in the AEC draft. This Anderson did by providing for a sliding, compulsory minimum of private insurance that each reactor operator would be required to carry. AEC would be responsible for determining the amount of basic private insurance required of each licensee as a condition of issuance of the license. The cost of private insurance would be one of the factors considered in fixing the level at which the Government indemnity begins to operate.

Other features of the Anderson bill:

- Liability of reactor operators would be limited to the amount of private insurance coverage required by AEC together with the amount made available under the Federal indemnity plan.
- The Government's liability is limited to $500-million in the aggregate for each facility in the U. S. and each incident.
- The U. S. would make a minimum annual charge per reactor for this coverage, the proceeds to be devoted to AEC research on nuclear safety.
- Procedures and standards for settlement of claims are established, to broaden protection of the public while protecting the Government against excessive settlements.
- AEC is authorized to extend Federal excess indemnity to its contractors as well as to licensees.

Anderson said JCAE would hold brief hearings both on his bill and on the AEC draft which Rep. Cole introduced (H.R.11242).

• • •

Meanwhile the pool of 70 capital stock casualty companies formed five months ago (NU, Feb. '56, p. 10), grown now to 110 firms, was formally organized as the Nuclear Energy Liability Insurance Association to underwrite private reactor hazards, with a $50-million third-party liability limit per reactor. Questioned at the Washington hearings, a representative told Sen. Anderson that all the country's 650 stock companies had been invited to participate, but that the 110 who accepted represent the overwhelming majority—about 90%—of the country's liability capacity. Likewise, the capital stock fire and property insurance companies, who had earlier announced a pool to provide $50-million coverage for reactor operators insuring their property against reactor damage, organized formally as the Nuclear Property Insurance Association. Of some 550 existing companies invited to join, 150 are members.

Both the liability and the property syndicates said they were not yet in a position to quote rates.

German Plans Described

Completing a whirlwind U. S. tour, Bonn's Minister for Atomic Affairs Franz Josef Strauss told NUCLEONICS that West Germany had asked the AEC for more than the 6 kg of enriched U provided for in the research bilateral, because she wishes to purchase three research reactors in the U. S.

He said he came here interested in buying two swimming pools of different types, and a water boiler; but that he had lost interest in the latter and was considering instead a sodium-graphite type, an Argonaut (*see* p. 22), or an LITR or ORR type. He said he hoped to sign purchase contracts with manufacturers "as soon as possible, in a few weeks," and then open negotiations with AEC for a power bilateral. Time of delivery for the research reactors will be 12–18 months, he indicated.

Of the three U. S.-bought reactors, one will be set up at a power reactor development school at Munich; the second swimming-pool at another power reactor center at Hamburg which will eventually concentrate on nuclear propulsion for ships, and the third near Frankfurt. A fourth center is contemplated for Cologne.

In addition, a national nuclear research center will be established at Karlsruhe. Here the first German-built research reactor—10-Mw heat, 2.5-Mw electricity—will be designed and built, along with laboratories, hot cells, a teaching institute. The Federal government, state governments and private industry will collaborate in this scheme, to take 2½–3 years.

AEC Asks More Uranium

Both extension and expansion of uranium procurement were set by AEC in separate moves. Both pointed to the coming of a transition from a Government-controlled to a commercial uranium market.

On the former, the long-awaited announcement finally came regarding the 1962 terminal date for guaranteed AEC purchase of all U production: AEC will continue the purchase program for an additional five years, to Dec. 31, 1966. It also will extend the initial production bonus for U ores from the present expiration date, Feb. 28, 1957, to March 31, 1960.

However, AEC set a price of $8 per pound of U_3O_8 contained in normal mill concentrates or precipitates, less than presently prevailing prices. Also AEC will retain an option to buy no more than 500 tons of U_3O_8 per year from any one mining operation; until 1962, AEC to buy all ore offered it. On the other hand, under the new procurement program AEC will let producers sell to licensed commercial users of uranium as well as to the Commission itself.

The move reassured the uranium industry, long worried about the 1962 deadline; but small operators complained that producers owning their own mills stood to benefit the most, as post-1962 prices are on concentrate rather than ore.

As to expansion, AEC has asked bids—due in the fall—for construction of additional feed-materials-plant capacity. AEC wants 5,000 tons a year more uranium oxide and fluoride for five years beginning 1959, hopes industry will build the first privately-owned feed materials plants to supply it—but has asked $22.2-million in the current budget to cover AEC construction if industry does not respond. Four companies (Vitro, National Lead, Mallinckrodt, Union Carbide) have spreadeagled the field till now, discouraged many smaller firms from trying to compete. AEC would like to have new blood in the program, so each of the four are teaming up with another company to make a proposal: Mallinckrodt with Climax Molybdenum, Vitro with Goodrich Chemical, Union Carbide Nuclear Co. with Catalytic Construction, and National Lead with Allied Chemical & Dye.

About the Industry

The sun had not yet set on the opening day of the country's first privately-financed reactor-fuel-element factory when its builder, Babcock & Wilcox, announced it would start at once to add 52,000 ft² to the existing 32,000. The multimillion-dollar addition, to be completed by November, will add three 50-ft production bays to the single one now adjoining a row of handsomely equipped laboratories. The Nuclear Facilities Plant, six miles east of Lynchburg, Va., in a bend of the James river, was built to supply fuel elements for AEC's MTR (NU, Dec. '55, p. 10; Jan. '56, p. 13) and to develop and produce similar, larger elements for Con Ed's 234-Mw Indian Point plant, which B&W is building. What the addition will house, B&W president Alfred Iddles declined to say ("We're going to develop new things—I don't know what they are. We have faith. It's not for any one thing that is known today.") However it is understood that—even though B&W last month got the nod from AEC to build the first pilot liquid-metal-fueled reactor—Lynchburg will remain a solid-fuel center. A considerable amount of production development, as distinct from scientific development, remains to be done: how to make fuel elements on an assembly-line basis and make money too.

Meanwhile it was learned that B&W had transferred the new Nuclear Facilities Plant from the atomic energy division to the boiler division. It explained this seemingly paradoxical turn this way: B&W has decided that atomic energy is here to stay and that the entire company is going to be involved in nuclear activities; so the atomic energy division will concentrate on development and design work, and straight production will be the domain of the boiler division.

Also unveiled at Lynchburg last month was the critical experiment facility, 1,200 yards from the fabrication building. Here a zero-power mock-up of the Indian Point reactor's core will permit calculation of the reactor's nuclear characteristics (*see* p. 102). Largest critical experiment ever made, according to B&W, in terms of the quantity of U^{235} used, it will use it in the form of oxide powder dispersed in polyethylene plastic tape—rather than solid metal—sandwiched between thorium blanket plates, for ease of handling and greater safety. (In the event of safety rod failure, rising power in the core will cause gas bubbles to form in the plastic, and this will force automatic shutdown.) B&W hopes to get the core mock-up critical by fall, has a full year of experiments planned. The building itself is flexible so that other critical experiments can be staged after completion of the work on the Con Ed job.

Incidentally, B&W has arranged for $10-million of insurance on the Lynchburg installation, through the company's regular carriers.

The nucleonics industry will be a voracious customer of stainless steel, according to Robert P. Petersen, director of nuclear research for Republic Steel. The Con Ed plant will use 100 tons in the reactor unit alone, he said; Republic supplied 300 tons for the *Seawolf*. By 1958, Republic expects to produce more than 500 tons annually for nuclear uses, and the entire industry shortly thereafter may be making 20,000 tons a year. Petersen also points out that as the price of uranium drops, it may become cheaper to use stainless with more U, to get more neutrons to overcome steel's higher neutron absorption cross section, and thus avoid expensive exotic materials.

Reactor News

Navy research reactor nears completion. Also the first reactor to be located in the Nation's capital, the swimming pool reactor being built at the Naval Research Laboratory is scheduled to be finished this month, together with "a number of special purpose research laboratories for use in conjunction with the reactor." The reactor and its associated research facilities are to be entirely unclassified.

Reactor program revelations. A host of new information came out during the AEC's presentation of its case against the Gore bill (*see* p. 17). Reactor development chief Kenneth Davis in his testimony before the Joint Congressional Committee on Atomic Energy, disclosed these facts:

- General Public Utilities Corp. has called for bids by July 1 on the building of a nuclear power station in Manila, P.I.
- Borax-3—like EBR-1—"ceased to operate because of a fuel element failure," in April, after operating at Arco for about six months at rated temperature and at electrical power levels up to about 2 Mw. A second core with new fuel elements is being developed and will be used in continuing the experiment as Borax-4. Initial operation is expected early in fiscal 1957.
- A zero-power fast critical assembly, ZPR-3, "operated successfully" at the National Reactor Testing Station at Arco during the first five months of 1956. This facility began operating in Oct. 1955 and is being used to provide accurate data necessary for detailed design of the EBR-2 core. Critical experiments for the EBR-2 core with U^{235} are continuing, and a Pu loading simulating the EBR-2 will be completed soon. Because of the heavy workload imposed on ZPR-3, consideration is being given to the construction of another zero-power fast critical assembly at Argonne.
- Study contracts have been negotiated with Ford Instrument Co. and with Studebaker-Packard Corp. to provide a better understanding of the potential economics of the gas-cooled concept and to delineate the research and development remaining to be accomplished. Battelle Memorial Institute has begun testing materials applicable to this reactor concept, and a contractor is being selected to design, construct and operate a gas-cooled reactor experiment for AEC.
- A new reactor approach is a recently-added project "primarily to test plutonium recycle techniques in thermal heterogeneous systems." AEC has asked GE at Hanford to submit plans for an r-&-d program covering the use of Pu in the operation of thermal heterogeneous power systems, and construction of a small experimental reactor is contemplated as the focal point of the program. Recycling Pu would have three important merits, Davis said: it may reduce fuel costs, it will net more power from a given U supply, and it will increase the usefulness of reactors in other countries requiring slightly enriched U by reducing the dependence of such reactors on isotope separation plants. Very little r-&-d work has been done in this field, Davis observed; the work planned will include reactor physics, reactor engineering and plutonium-recycling metallurgy.
- In Canada, there is being considered a 100- to 200-Mw low-cost nuclear power station, and several small package power reactors.
- In Belgium, a high-flux engineering research reactor is planned at Mol for completion in 1958 (NU, Feb. '56, p. 13), and negotiations are underway with Nuclear Development Corp. of America for design studies. The Belgians are also considering a medical reactor for Mol. They want a 150-Mw power reactor by about 1961.

A&FP buys two reactors. General Electric and Atomics International were chosen to supply two of the three 10-Mw power reactors American & Foreign Power plans to install in Latin America. GE offered a single-cycle boiling-water reactor using stainless-steel-clad uranium-oxide rods having a warranted life of 15 months at 80% load factor. AI's proposal was for an organic-moderated plant, contingent on success of AEC's current OMRE projects; AI also warranted aluminum-clad uranium plate fuel elements for 15 months. Final decision has not yet been reached as to the manufacturer of the third reactor still to be purchased; Alco, AMF Atomics, Westinghouse, and Babcock & Wilcox with Allis-Chalmers were the other bidders. A&FP said it was not yet in a position to announce the names of the countries where the plants will be installed, because no Latin American country has as yet completed negotiations for a power bilateral. Brazil is considered certain to be one of the three, and Mexico, Cuba and Guatemala are said to be in the forefront for the other two.

Daystrom to build BNL medical reactor. Daystrom has landed a contract to build the Brookhaven medical reactor. This will be the first complete reactor job for Daystrom, hitherto an instrument and component supplier. Daystrom will build the core and console, do the wiring, subcontract the rest. The firm has also centralized the administration of its nuclear program, and set up new headquarters at Elizabeth, N. J.

A ninth reactor concept? AEC is understood to be interested in an additional approach, a fluidized uranium slurry reactor. Here, graphite pellets of micron size, coated with uranium, would be circulated through the reactor core. The project is understood to be underway at Rice Institute. However, AEC reactor chief Kenneth Davis says that this is still "just something strictly in the exploratory stage—a long way from a reactor experiment."

Argonaut a useful educational tool. Argonne National Laboratory's Argonaut has stirred up considerable interest in university circles looking for simple, safe, and inexpensive nuclear teaching reactors. The Argonaut (the name derives from Argonne-naught—naught because it is essentially zero-power) is described as being "not only fool-proof but student-proof"; in addition it uses uranium of less than 20% enrichment, and can be built for less than $100,000. The core consists of annular aluminum tanks of 2 and 3 feet diameter, with Borax-type fuel elements placed in the annulus, separated by graphite blocks, and immersed in water moderator; an internal thermal column occupies the inner tank. The reactor is capable only of brief operation at 10 kw maximum; the primary safety system, giving fast and absolute shutdown, is effected by nitrogen injection to decrease moderator bulk density; simultaneously the water moderator is dumped through a quick-opening valve.

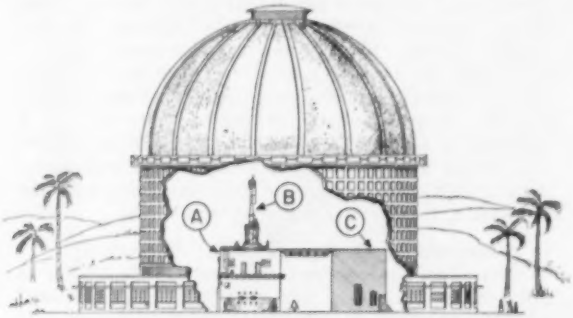
Third ANP reactor at Convair. A 10-Mw (heat) reactor to test radiation effects will be built by Convair at its Forth Worth, Tex., nuclear airplane facility. Convair already has one small reactor that can be hoisted on a crane, and another installed in a conventionally-propelled B-36, for radiation shielding tests.

Spain gets U. S. aid. Like Brazil (NU, May '56, p. 23), Spain has been granted $350,000 U. S. aid toward the cost of the research reactor she is buying from GE.

World News

Soviet AEC set up. *Pravda* recently reported establishment of the Main Administration on Atomic Energy and the naming of Efim Pavlovich Slavsky to head it. In the past, it is believed, responsibility for nuclear energy development was divided among several bodies, principally the Academy of Sciences, the Ministry of Electric Power Stations (Georgi Malenkov's ministry after his demotion from the premiership), and the Soviet Armed Forces Ministries. The new body will be charged with developing nuclear reactors for electric power stations, and scientific research and development on all phases of nuclear development other than military. The announcement fails to mention military uses of nuclear energy, and the task of the new administration apparently will exclude control over the military. The step follows closely the establishment of the Central Institute for Nuclear Research (NU, May '56, p. 23), which will coordinate nuclear research in all Soviet satellites with that of Russia.

CIR agreement signed. Under an agreement signed in New Delhi by Indian Premier Jawaharlal Nehru and Canadian High Commissioner Escott Reid, Canada will contribute slightly more than half the $14-million cost



of CIR (Canada-India Reactor), the NRX copy that Ottawa offered India under the Colombo plan. Canada is supplying the reactor itself and steel for the hermetically-sealed steel rotunda, 135 ft high and 120 ft in diameter, and is doing all the design work; total value of her contribution is $7.5-million. Indian contractors and labor will do most of the construction work at the site; value of the Indian contribution is more than $6.5-million. Canada will supervise engineering and erection, and is training Indian technical personnel in operation of NRX at Chalk River. Work on the foundations and basement has already started at the site on Trombay Island, seven miles NE of Bombay, and should be completed by the end of this month. Erection of the steel rotunda will start soon after the monsoon this year and will be finished by year's end; the reactor is scheduled for operation by mid-1958. Adjoining sketch shows *A*, the reactor; *B*, the fuel-rod removal flask, and *C*, the storage block. Spent elements are drawn out of the core and up into the 25-ton lead-lined flask, which then moves across the bridge over the concrete storage block and lowers the "hot" rods into the block and onto a carriage that travels in a water-filled trench to the chemical processing plant. A revolving crane operates at the base of the cupola. Laboratories, offices and equipment rooms surround the base of the rotunda, outside the airtight shell. Among improvements to the original NRX design being incorporated in CIR by Shawinigan Engineering Co. Ltd. of Montreal are: more extensive facilities for experiments on power reactor development, more holes through the shielding for basic physics experimentation, and advanced control and instrumentation.

Calder Hall "A" goes critical. On May 22 the first of the two reactors comprising Britain's first full-scale nuclear central station was brought to criticality. Fuel-loading had started at the end of April, after completion of stringent pressure tests on the reactor pressure vessel, and after loading of more than 1,000 tons of graphite moderator. Physical measurements and instrument checks are now taking place; steam produced now is dumped through a large condenser. Sometime in August it is expected that tests of operation at fractional load will have been completed, and only then will the turbogenerators be started up. Two months later, on Oct. 17, Queen Elizabeth will visit Calder Hall to open the station officially.

Portugal plans moves. By the end of 1957, Portugal will have completed a nuclear physics and engineering laboratory, according to José Frederico Ulrich, president of the Portuguese Board of Nuclear Energy. It will be equipped with a research reactor, one or two particle accelerators, a pilot plant for producing pure uranium from ore, and a chemical lab for nuclear metallurgy research; it will be available to Portuguese universities for teaching of nuclear science.

Research reactor for Hungary. Last month construction began on Liberty Hill overlooking Budapest on the country's first research reactor. According to *Népszava* ("The People's Voice," a Budapest Communist daily), "Soviet plans are being used for the entire institute, which will be composed of one central building and several attached laboratories. Soviet technicians and engineers are scheduled to fit Soviet reactor parts into the main building during the spring of 1957."

South African U production still climbing. Exports of "prescribed materials" (almost entirely uranium) are now running at over $8.5-million a month and should be considerably higher by year's end. Five new producers are just starting operations. The country's uranium industry will have earned about $980-million by 1965 when the 10-year contract with the U. S. and U. K. expires, according to Secretary of the Atomic Energy Board J. Reid. Production of U will reach $140-million a year when resources are fully developed (20 of 27 gold mines producing uranium are already supplying it); this estimate compares with a $112-million estimate made only five months ago (NU, Jan. '56, p. 15).

U strike in Colombia. Extensive pitchblende deposits are reported in the municipality of California, Santander province in NW Colombia. The Ministry of Mines and Oil will entertain proposals for exploitation. The government is already considering a contract with Electric Mines Corp., a U. S. firm, for exportation of uranium ore.

Nuclear ship blueprints ready. The Foundation for Shipbuilding Research, Göteborg, Sweden, is now completing blueprints for a nuclear propulsion plant for ships delivering 20,000 shp from "low-content uranium" with a 21-month reloading cycle. The Swedes feel if they are not to lose out in international competition they must start building such ships within 10 years.

ROUNDUP

News in Brief

First Fermi award to Von Neumann. In recognition of "outstanding contributions to the theory, design and construction of fast electronic computing machines," the first Enrico Fermi award of a medal, a citation, and $50,000 was conferred on Commissioner John von Neumann by the AEC. Fermi himself was the only prior recipient of the award, which was given his name after his death. Said the General Advisory Committee: "The fact that the use of these machines, all developed almost within a decade, is now commonplace in industry, in business, and in military, engineering, meteorological and scientific applications is largely due to Dr. von Neumann's direct contributions and inspired direction. In the control and use of atomic energy for military or peaceful purposes, which was central in Dr. von Neumann's mind in the development of these machines, they are indispensable."

Vienna to be world's atom capital. Both the United States and the USSR endorsed Vienna as the permanent headquarters of the proposed International Atomic Energy Agency (NU, May '56, p. 17).

Supplementary AEC funds asked. An additional $112.5-million for the AEC was asked of Congress for the fiscal 1957 budget to speed development and production both of weapons and civilian power plants. $88.4-million would go for operating expenses, $24.1-million for capital expenses. The regular AEC budget for next year calls for $1.8-billion.

QM planning food-processing center. A pilot plant for food irradiation is to be in operation by the end of 1958. Bids are due June 20 on an accelerator capable of giving 1,000 tons/month a 2-million rep dose based on the unit density of the material, working 24 hours a day, 28 days a month. The plant also will have a beta source that the Army Quartermaster Corps will purchase, and a reactor that AEC is developing and will build. Oak Ridge and Argonne National Laboratories and Internuclear Co. of St. Louis have study contracts on that project, but neither the reactor type nor the site has yet been chosen.

Industrial nuclear technology session a success. The two-day conference on applied uses of radiation held in Chicago last month by Armour Research Foundation and NUCLEONICS drew nearly 500 persons. Plans are being laid for a second such meeting next year.

Euratom a step closer. At a meeting of the foreign ministers of "Little Europe"—France, Italy, West Germany, Netherlands, Belgium and Luxembourg—in Venice the technical report on Euratom (NU, Dec. '55, p. 11; March '56, p. 23) was adopted as basis of discussion for a treaty. Treaty-drafting will start June 26 in Brussels where the ministers will meet again.

Olin Mathieson in fuel field. A new nuclear fuel division has been set up by Olin Mathieson Chemical Corp., with headquarters in New Haven, Conn.

Curtiss-Wright to build lab. A nuclear materials laboratory with a research reactor and hot cells is planned for the 80-mi² research and development center Curtiss-Wright Corp. is setting up at Quehanna, Pa., 25 mi NW of University Park in the central part of the state. The new facilities will be used both for support of defense production and for peacetime applications of nuclear energy.

Nuclear course for industry repeated. North Carolina State College will give, for the second summer, a course in nuclear engineering fundamentals for industry, at Raleigh July 2–28. The course will cover nuclear power developments, reactor theory and design, chemical processing, safety and health aspects, and basic nuclear physics.

Work underway on AEC headquarters. An $8.83-million bid by John McShain Inc. of Philadelphia was lowest of 13 and won for the firm the construction job on AEC's 400,000-ft², 4-story headquarters at Germantown, Md., 23 mi NW of Washington (NU, Jan. '56, p. 11). Work at the site has begun and the building is to be completed by late 1957.

OMRE approaches construction stage. Idaho Operations Office of AEC was to open bids early this month on a contract for construction of buildings, utilities, services and roadways for the $180,000 Organic Moderated Reactor Experiment at the National Reactor Testing Station. Idaho Operations also announced that the Ralph M. Parsons Co. of Los Angeles had been given a contract for architect-engineering of test facilities for the aircraft nuclear propulsion area at NRTS operated by General Electric. The $12-million facilities will include a test building, shielded control and equipment building, and supporting facilities; design will take 10 months, construction will start next spring.

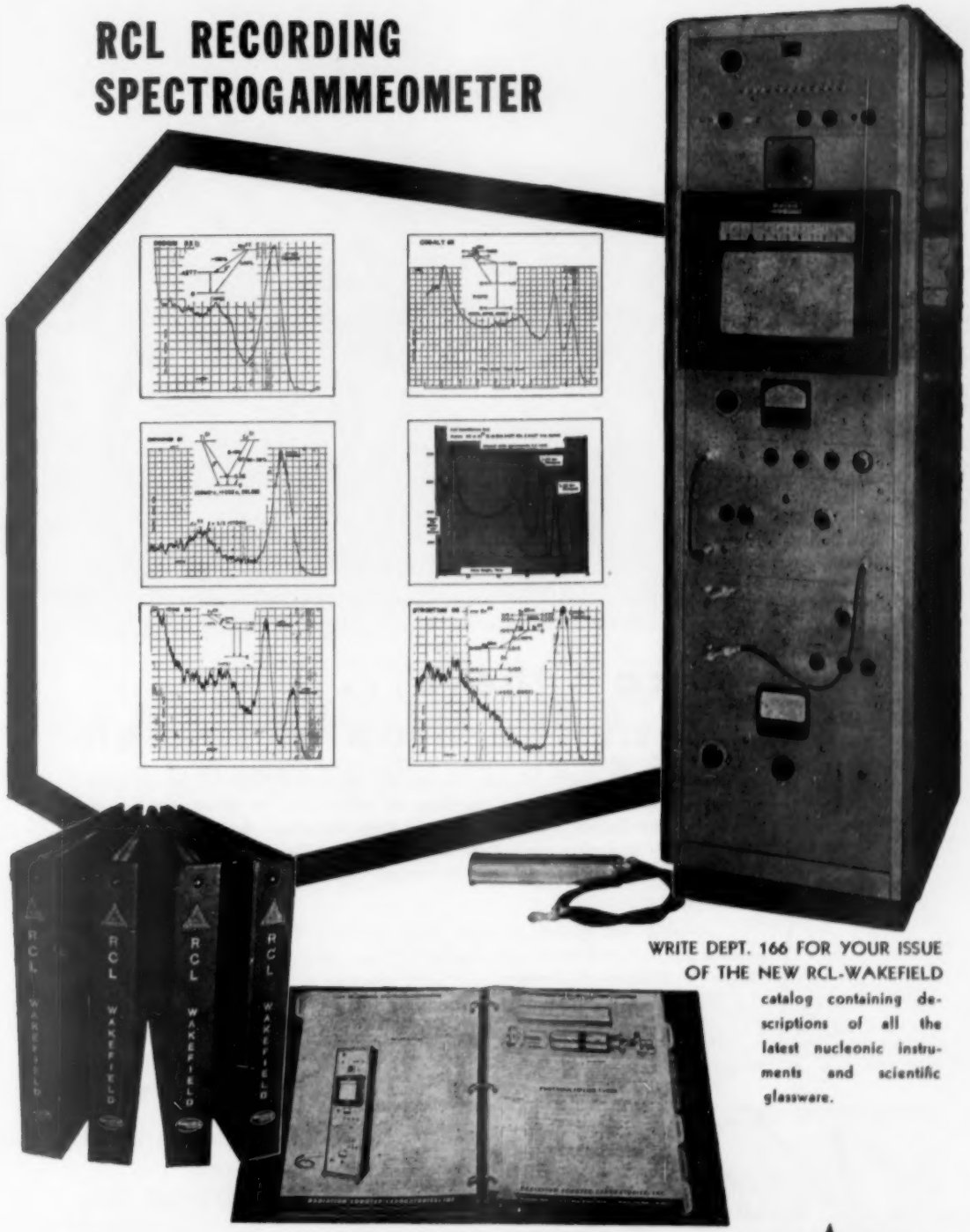
U production at Orphan to start. Western Gold & Uranium Inc. has obtained sufficient private capital to bring into production this month its big "Orphan" pitchblende lode (NU, Jan. '56, p. 16).

Zirconium blast under probe. AEC and Union Carbide Nuclear Co. are investigating an explosion of "one or more" drums of zirconium oxide and zirconium scrap metal in a salvage yard at Oak Ridge's Y-12 area last month. Two of three men working 30 to 40 feet away were killed, the third is in serious condition. Like Ti, Al, and some other metals, Zr in chip or oxide form is pyrophoric and should be kept under oil. Another, earlier Zr incident came to light recently: a year ago 150,000 lbs of Zr went up at Bettis, destroying a storage building.

Detroit Edison starts site work. Grading, improvement of an access road, and other site-preparation work will be started at Lagoona Beach, 30 mi south of Detroit, where Detroit Edison and 25 partners in the Power Reactor Development Co. plan to build a 100-Mw fast breeder power station (NU, Feb. '56, p. 16; April, p. 22).

GE gets paid. A check for $1 was handed by AEC to GE as compensation for its having operated for ten years two huge AEC installations—the $1-billion Hanford Plutonium works and the Knolls Atomic Power Laboratory (but $97,000 monthly administration expense has been reimbursed). Under a new five-year contract, GE's fee for continuing to operate the plants will be raised from ten cents to $2.65-million a year, and the company will assume some indirect and overhead expenses, liabilities, and business risks formerly carried by the government.

RCL RECORDING SPECTROGAMMEOMETER



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The U. S. S. Boston (CAG-1), the Navy's first guided missile cruiser, with Terrier Missiles and their launchers at the stern.

NAVY BUREAU OF ORDNANCE DEVELOPS WEAPON SYSTEMS FOR USE AGAINST ATTACK BY SEA OR AIR

The recent unveiling of the Navy's first ready-for-combat anti-aircraft guided missile weapon system —TERRIER—is but one result of the research and development work being done by the U. S. Navy's Bureau of Ordnance and a coordinated team of industrial and educational institutions.

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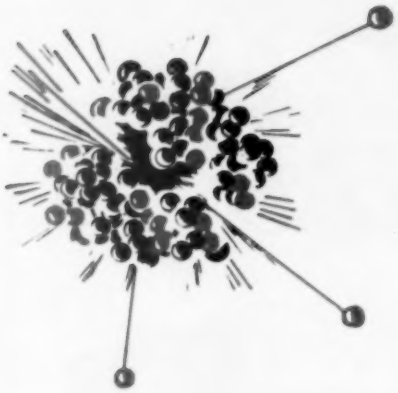

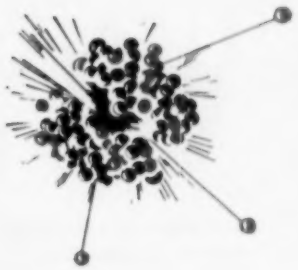

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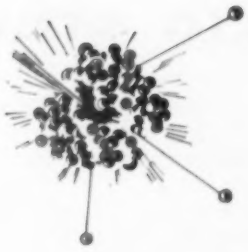

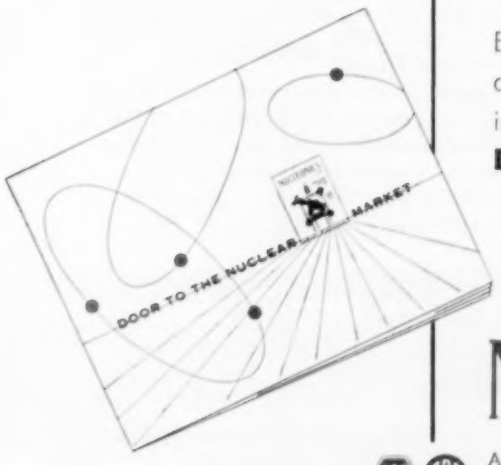

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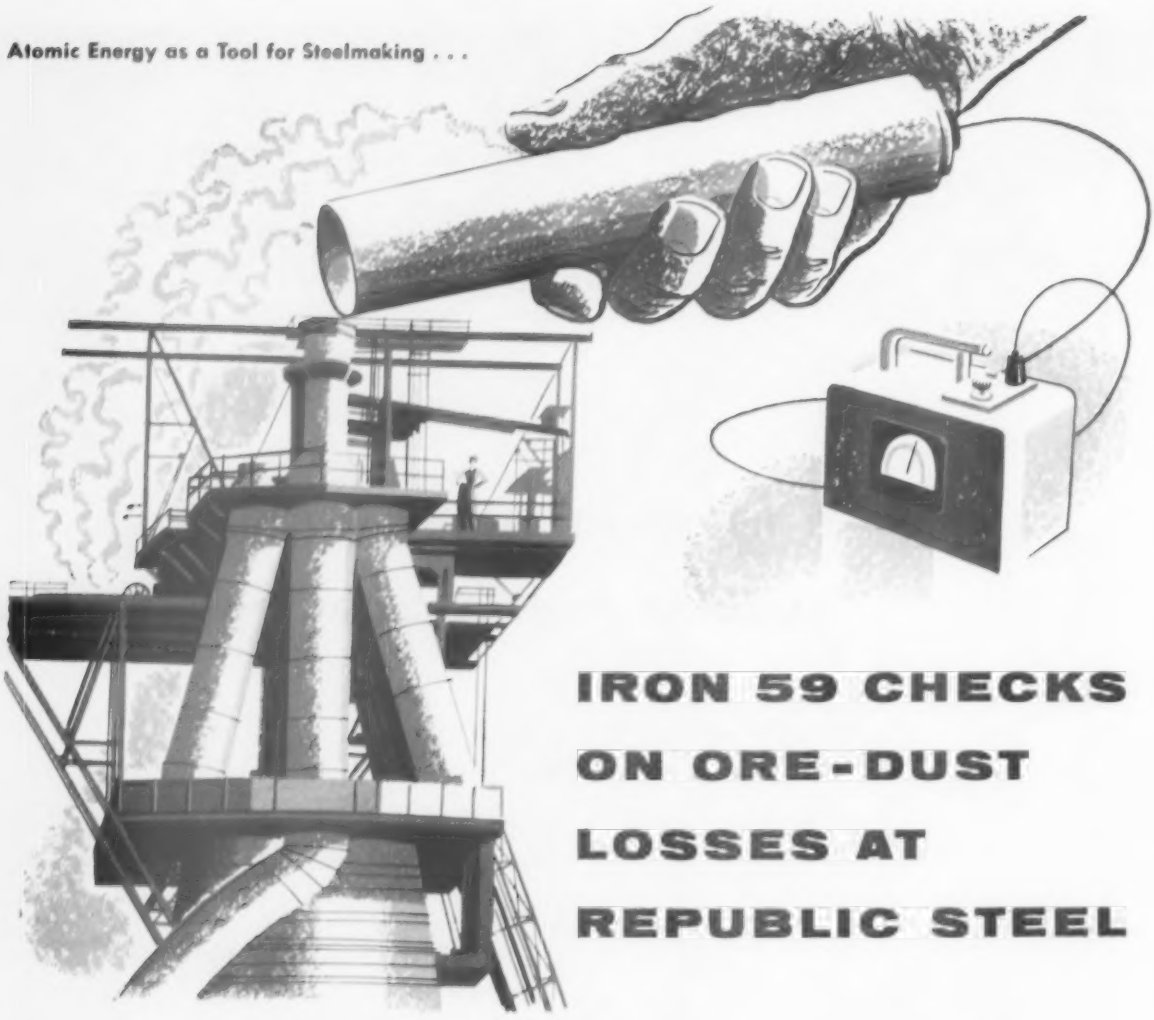

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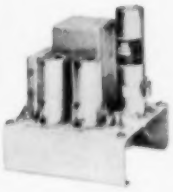

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Sylvania entered the atomic energy field ten years ago, and was a pioneer in the development of nuclear fuels. The new expansion program is a pioneering one, too—leading, it is hoped, to a large-scale competitive, privately financed nuclear energy industry that was envisioned in the Atomic Energy Act of 1954. The new production and engineering facilities will be owned entirely by Sylvania.

It is estimated that, by 1970, 5 per cent of the nation's generating capacity will be nuclear-powered; by 1980, the nuclear-powered capacity is expected to reach 20 per cent of the total. Sylvania's long-range aim is to provide a completely integrated "out-of-pile" fuel and reprocessing service for the power industry.

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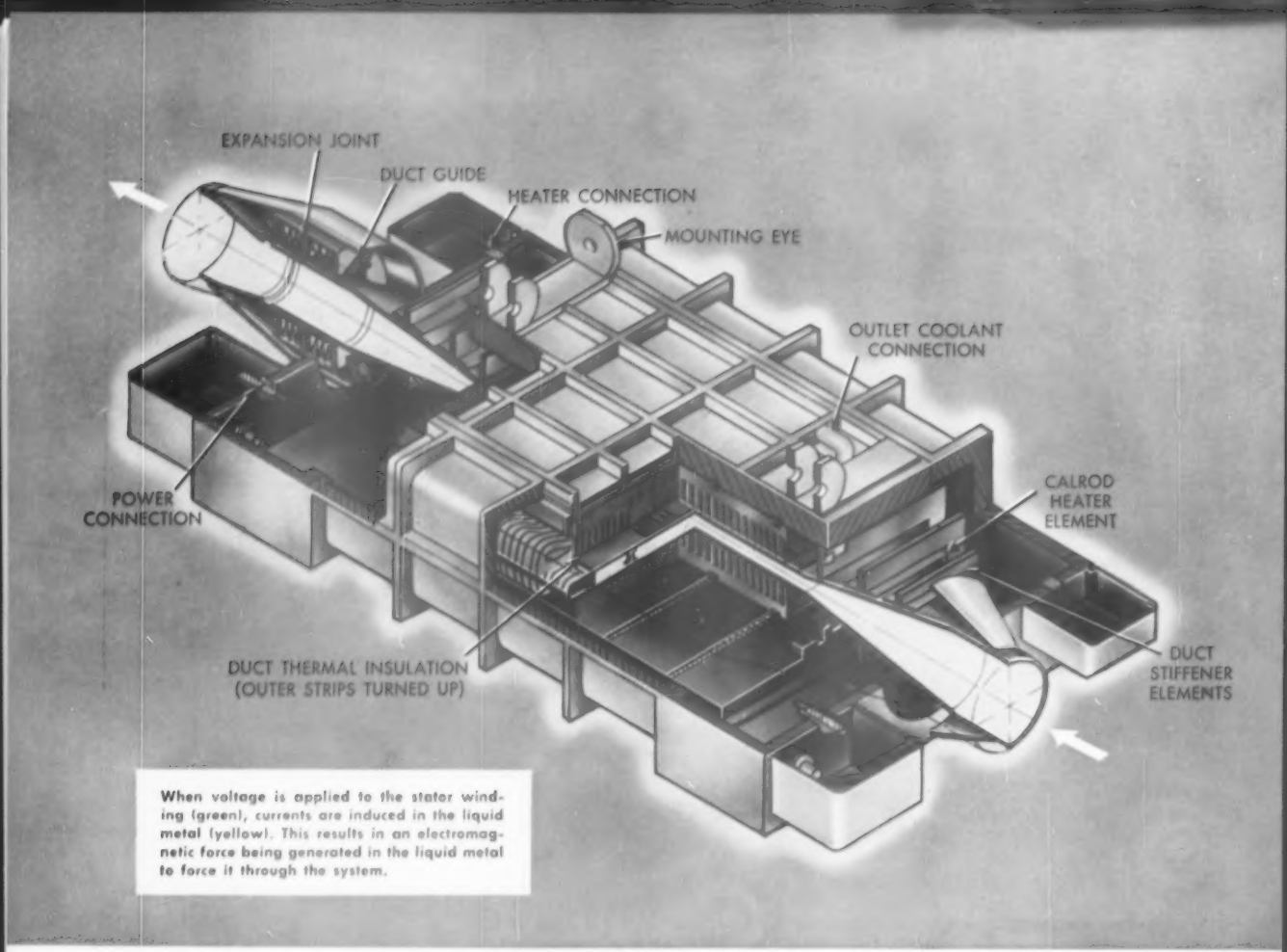
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A Letter on EBR-I Fuel Meltdown

(EDITOR'S NOTE—*Although this "letter to the Editor" was not intended to be in reply to the editorial on the same subject that appeared here last month, the importance of and interest in the subject is so great that we wanted to display it prominently. Dr. Zinn, the author of this letter, had primary responsibility for EBR-I.*)

To the Editor:

This letter concerns the melting of some of the fuel elements of the Experimental Breeder Reactor on November 29, 1955 and the news stories and the AEC press release that subsequently have appeared. I am compelled to write this letter because of the hope that its publication will establish that this event is not pertinent to the hazard problem in the operation of nuclear power plants or the writing of insurance for such power plants, as has been claimed in some news reports.

As far as I know, it never has been claimed by anyone who is knowledgeable in reactor technology that, under the proper circumstances, fuel elements of metallic construction could not be melted in a reactor. In the EBR-I case, the experiment in hand was of such nature that it fully qualified as a proper circumstance. In this letter, some detailed information about the event is given so that its relation to power plant operation can be judged.

1. EBR-I has been used for a number of years in an experimental program, mostly in the physics of fast reactors. The reactor was scheduled to be placed in standby early in 1956, and the fuel was to be sent to chemical processing and not replaced unless new experimental uses developed. This decision was made because all experiments that were practical to perform and that might be expected to yield useful results had been carried out, and because there had been placed into operation at the same site a new zero-power reactor of much greater versatility. As a last experiment, however, it was decided to make measurements on transient temperature coefficients. Briefly, the experiments consisted of measuring changes in reactivity of the reactor as the temperature of the fuel elements was increased. By far the most difficult part of these experiments involved placing the reactor on a short positive period and permitting the fuel temperature to rise to 500 or 600° C. Because it was desired to obtain the temperature coefficient of the fuel only, it was necessary to shut off the flow of the liquid-metal coolant. Therefore, it can be said that the experiments were done not on an operating reactor but actually on a critical assembly.

2. Two details of the design of EBR-I should be in mind in considering this experiment. First, the fuel elements of EBR-I are cylindrical rods of diameter slightly under one-half inch. The uranium fuel cylinder is bonded by liquid metal to the stainless-steel cylindrical jacket. Second, because EBR-I is an experimental tool, the design called for the fuel elements to be removable individually although it would have been much simpler to have fastened the fuel elements to each other in a compact core. Because each fuel element has to be removable individually, it passes through a holding plate for which the average clearance between the hole of the holding plate and the fuel element jacket is only six-thousandths of an inch. This means that a small amount of distortion of the jacket is sufficient to prevent the removal of the fuel element from the core. Because of the liquid metal bonding, the uranium part of the fuel element can distort without producing distortion in the jacket. This feature of design has been so successful that in the almost five years of use of the reactor, no fuel jacket has distorted sufficiently to fail to pass through the holding plates although there have been a number of difficult-to-remove rods.

However, in the original design it had been anticipated that such distortion might occur. In that event, it was expected that the whole core assembly would be lifted out of the reactor tank and disassembled in order to remove the fuel. This, in fact, is the method which

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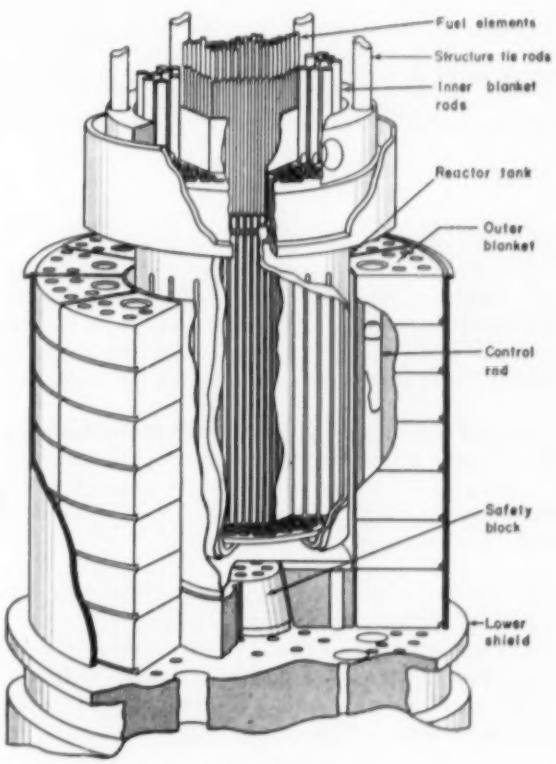

Cutaway of EBR-I

WHAT KURCHATOV SAID AT HARWELL

PRELUDE TO DRAMA. Kurchatov, flanked by Bulganin and Khrushchev, tours Harwell. Import Russians attached to Kurchatov's speech is pointed up by official character of visit to Britain

Russian Thermonuclear Experiments

The Russians have experimented extensively with high-temperature discharges in deuterium gas as one approach to thermonuclear power. Neutrons and X-rays have been produced—the first reported instance of this. But limitations have lead the Russians to bet on "stationary" processes

EDITOR'S NOTE—The most dramatic and significant event since the Geneva conference came with Russian scientist Igor Kurchatov's astonishing talk on fusion power, delivered during a visit to Harwell on April 26. With this one speech the Russians moved well ahead of the U. S. in the extent of declassification of thermonuclear information. In light of its importance we are publishing Kurchatov's speech here with commentary by scientists in the field.

It is impossible to say just how much of the Russian program Kurchatov revealed, but it is clear that he gave a responsible account of experiments basic to eventual realization of controlled thermonuclear power. He certainly impressed his British listeners. And while U. S. AEC observers generally won't comment, they all imply that his speech was quite good. Certainly those outside the AEC were impressed.

We think it is unfortunate that the initiative in this field was left to the USSR. We have long urged declassification of fusion-power experiments. We feel that the reason advanced for continued classification in this area—that fusion reactors will be a source of neutrons and hence might be used in the production of special nuclear materials—is inadequate in light of the universal availability of fission neutrons. Opening up the subject of thermonuclear power will speed realization of this new source of power.

Official Reactions to Kurchatov's Speech

Western governments have felt increased pressure for declassifying information on thermonuclear power as a result of Kurchatov's speech. To learn what action might be forthcoming, NUCLEONICS *addressed the following questions to responsible officials here and abroad, and got the replies shown below.*

> *Is it your impression Soviet talk indicates any important advance in work on controlled fusion? To your knowledge does Soviet talk represent release of information hitherto unreleased? Do you have any plans for any further information release on controlled fusion? If so, of what nature? Do you think there is any need for expansion of unclassified discussion of the subject?*

Lewis L. Strauss, *Chairman, US Atomic Energy Commission—*

. . . It is my impression that the article contains no information not long since known to our people working in this area.

As to your inquiry whether the Atomic Energy Commission plans any further issuance of unclassified information on the subject, I can only say that at this moment, I do not know. You will understand, I am sure, that I cannot forecast future actions by the Commission, being one of five members who reach decisions as a group, and for this reason consequently I cannot respond to your query on the likelihood of declassification of developments in any area presently classified.

Sir Edwin Plowden, *Chairman, UK Atomic Energy Authority—*

Work to discover whether the thermonuclear reaction can be controlled is going on in the UK. It is not the present intention of the UK Atomic Energy Authority to make any further release of information on this subject.

Clinton D. Anderson, *Chairman, Joint Committee on Atomic Energy—*

Congratulations on publishing the Kurchatov talk on controlled fusion. The very fact that such a paper was delivered in England in an unclassified status is important in itself.

I certainly believe there is great need for more unclassified discussion on controlled fusion. The research which is going on in the field is essentially basic scientific work and needs to have the best of our academic scientific brains trained on the problem. Too often the best ideas in basic long-range theory come from people who are entering the field for the first time with brilliant minds, a fresh perspective, and untrammeled by security restrictions—people who are able to think and talk freely. To me, classification of this program merely proves that we lose our main strength in our traditional freedom to search for new ideas when we try to classify basic scientific work such as controlled fusion.

What follows is the complete English text of the lecture given by Igor V. Kurchatov at Harwell, England, on thermonuclear experiments of the Academy of Sciences of the USSR. Boldface comments are by U. S. scientists.*

OF FOREMOST SIGNIFICANCE among the more important problems of modern engineering science is the utilization of energy of thermonuclear reactions. Physicists over the whole world are attracted by this extraordinarily interesting and very difficult task of controlling thermonuclear reactions.

Investigations in this field are being carried out by Academician Artsimovich at our Institute. A leading role in the theoretical investigations was played by Academician M. A. Leontovich.†

As is well known, thermonuclear reactions can arise if the temperature of matter is sufficiently high for atomic nuclei to surmount the forces of the Coulomb barrier with appreciable probability during thermal collisions. The excitation of thermonuclear reactions in deuterium or in a mixture of deuterium and tritium is especially interesting as in this case a noticeable effect should be obtainable at relatively low temperatures.

Physics is indebted to the founder of nuclear physics, Ernest Rutherford, for information regarding the interaction of deuterons. In one of his last investigations Rutherford studied the nuclear reactions that occur when two deuterons collide. It was difficult to suspect at that time that the new facts discovered by him would make more realistic our hope of mastering the energy sources that up to now have existed only in the hot remote parts of the sun and distant stars that shine above us.

The intensity of thermonuclear reactions in deuterium

---

* [Igor V. Kurchatov, 53, occupies a high position in Russian nuclear affairs—he is rumored to be in charge of production of fissionable materials. He was elected to the Academy during the war. Before the war he was head of the nuclear physics laboratory at Joffe's Leningrad Physical-Technical Institute.]

† [Lev A. Artsimovich, 47, is in charge of the Russian thermonuclear work. He was elected to the Academy of Sciences in 1953 along with A. D. Sakharov and I. Y. Tamm, mentioned later. Artsimovich's work has been in the fields of electron optics and accelerators. Mikhail A. Leontovich, 53, was elected Academician in 1946; his work in the field of propagation of radio wave won him a Popov prize.]

should greatly increase with the temperature up to temperatures of several billion degrees.

Conditions for Fusion

A notion regarding the conditions under which thermonuclear reactions should be experimentally observable can be obtained by considering some concrete cases.

In deuterium whose density equals that of a solid body under normal conditions a temperature of 2×10^8 °C would be required to obtain 1 neutron/sec/gm of deuterium. If the deuterium were a highly rarified gas with a concentration of about 10^{12} atoms/cm³ a temperature of about 5×10^8 °C would be required to produce some effect in a gram of deuterium, which would occupy a volume of 30,000 m³.

Calculations necessary here are not difficult . . . the cross section for the d-d reaction as a function of energy is well known, and at low energies is dominated by the Gamow penetration factor. One need then account for the frequency and relative velocity of collisions (available from the same kinetic theory that governs the behavior of gases) and the likelihood that each results in fusion and the production of a neutron.

Thus, even to approach the threshold for production of thermonuclear processes the temperature of matter must be raised to a very high level. At such temperatures and under stationary conditions the deuterium should be an almost totally ionized plasma.

The amount of energy that must be concentrated in the plasma to raise its temperature to a level sufficient for the production of intense thermonuclear reactions should be comparatively small. Thus, the amount of thermal energy necessary to raise the temperature of 1 gm of deuterium to 10^8 °C equals only a few kilowatt-hours. This is about the same amount of energy required to boil water in a family samovar.

Therefore, if one were able to invent a method of heating the plasma with practically no thermal losses, even a low-power energy source could be used to induce intense thermonuclear processes. The main problem is to exclude heat losses, which rapidly increase with the temperature since the thermal conductivity of the plasma is proportional to $T^{5/2}$.

If matter is heated to a temperature of only several tens of thousand degrees in the absence of thermal insulation, the losses will be so great that further increase of temperature will be practically impossible.

There is another obstacle that arises when dense substances are heated: one must overcome the enormous mechanical forces that result from increase of the pressure with temperature. On heating initially solid or liquid deuterium we find that already at $T = 10^8$ °C the pressure exceeds 10^6 atm. Therefore, thermonuclear reactions can be induced only during a very short period of

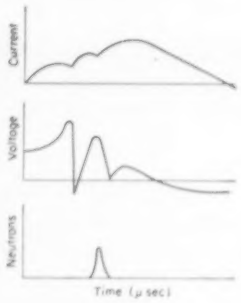

FIG. 1. Typical history of high-current discharge. In deuterium, neutrons are produced at time of second kink in curve of current vs time. No scale was provided, but total duration is 3–30 μsec, peak currents about 1-million amp, and voltages of order of tens of kilovolts

Digest of Kurchatov's Talk

The fusion of light nuclei releases energy. If we could get substantial numbers of light nuclei to fuse in a controlled fashion a new source of power would be available to man. However the fusion reaction is reasonably probable only when the particles have sufficient kinetic energy to overcome the repulsive electric force acting between them. For many particles to have such energies the assemblage must be at extremely high temperatures, hundreds of millions of degrees. However, even at temperatures as "low" as 200,000° C one expects some energy-producing fusion—about 1 d-d reaction/sec/gm of deuterium.

At these temperatures deuterium is an almost totally ionized plasma. The thermal conductivity of a plasma is so high that heat losses would make it impossible to reach temperatures much above several tens of thousands of degrees unless some way were found to insulate the plasma. No material container can be used because these all are vaporized at the temperatures of interest. Fortunately magnetic fields can be used to constrain the plasma, thereby lowering its thermal conductivity.

In particular, if intense currents are passed through the plasma a magnetic field will be generated that will serve to pinch the plasma onto the axis of current flow. Simultaneously the current will heat the plasma. If the whole thing holds together long enough for an appreciable fraction of the deuterons to fuse this could have the makings of a thermonuclear reactor.

Discharges were studied most in deuterium at low pressures, 0.005–10 mm. Discharge tubes were cylinders of various sizes. Discharge currents were 0.1–2-million amp at 10–40 kv. Peak power input was 40-million kw.

Typically the discharge begins at the outside wall of the cylinder and spreads toward the axis. The self-magnetic field of the very high current causes the discharge to collapse onto the axis, but it reexpands after reaching a minimum size. This is followed by a second contraction as the magnetic forces again draw the discharge toward the axis. It is during this second contraction that strong electric fields are established along the axis and accelerate the ions there, leading to the production of neutrons and X-rays. A third contraction and expansion phase is sometimes observed but never more. Thus neutrons are not produced as the result of reaching truly thermonuclear temperatures.

The transient nature of the whole process makes it less promising than continuous processes, which Kurchatov refers to but never specifies.

time in dense substances and such a process will always resemble an explosion (which, however, may not be dangerous) or a brief pulse.

Controlling Thermonuclear Reactors

On considering the various ways of generating intense controllable thermonuclear processes one finds that there are quite a number of directions that can be followed in attempting to solve this problem.

On the one hand, there are the approaches that lead to stationary thermonuclear reactions, and on the other,

> ***Kurchatov says practically nothing about stationary processes except to indicate their existence as an alternative to the pulsed discharges considered here. One kind of stationary process would be an accelerator delivering a beam of deuterons to a deuterium target, but it is known that such a scheme is hopelessly inefficient, at least for the case of a cold target. For any process where the whole mass of gas is kept at a temperature sufficient for fusion, radiation losses place impossible demands on the specific energy output of the reaction for bodies of reasonable size (NU, Nov. '55, p. 62).***
>
> ***Our sun provides an example of a stationary fusion process with surface temperature much lower than that in its interior; a useful approach might be to consider ways to scale it down to laboratory size.***

those that are based on the idea of utilizing an instantaneous temperature rise in transient processes of very brief duration. However, irrespective of the way the investigation is carried out, there is one problem that is inevitably encountered, namely, the isolation of the plasma heated to a high temperature from the walls of the vessel in which it is confined. In other words, a means must be found to keep the fast particles within the plasma over a period sufficient for the particles to have a good chance to react with each other.

One of the ideas proposed in connection with this problem was that of using a magnetic field for thermal insulation of the plasma. Academicians Sakharov and Tamm were the first to point out this possibility in 1950.*

> ***"The idea of using a magnetic field for thermal insulation of the plasma has been known to Western scientists for some years. It was, for example, well known to me in 1947 when I started a theoretical and experimental study of high-current arcs in strong magnetic fields. See Proc. Phys. Soc. B, 63, 795 (1950) and 65, 329 and 345 (1952)."—K. S. W. Champion, Tufts University.***

In a sufficiently strong magnetic field, electrons and ions can move freely only along the lines of magnetic force. In a plane normal to these lines of force the particles will move along circles of small radius. The positions of the centers of these circles can vary only as a result of collisions, each collision displacing the center by a distance of the same order of magnitude as the radius of curvature of the particle trajectory. If the radius of curvature of the trajectory is small compared to the mean free path, diffusion of the particles and thermal conductivity of the plasma in the plane normal to the magnetic field will be greatly diminished.

* [Andrei D. Sakharov, 35, is the youngest of the Soviet scientists mentioned by Kurchatov. His work has been in the field of electron physics and electron optics. Igor Ye. Tamm is the oldest, born in 1895. He has an international reputation as a theoretical physicist having contributed in such fields as cosmic rays, elementary-particle theory, theory of the Cerenkov effect, and quantum field theory.]

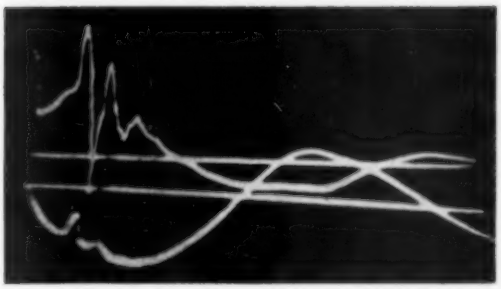

FIG. 2. Dual-trace oscillogram of current (bottom trace) and voltage (top) in a discharge in deuterium. Initial voltage was 40 kv; initial pressure was 0.05 mm Hg. Note that more of the cycle is shown here than in Fig. 1

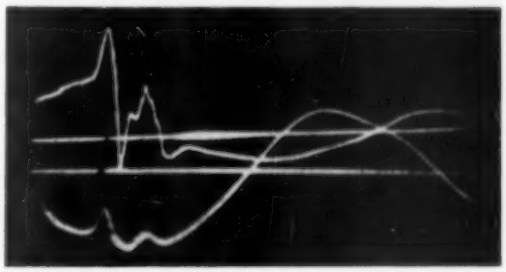

FIG. 3. Oscillogram of current and voltage in a discharge in deuterium at somewhat higher initial pressure, 0.2 mm Hg. As in Fig. 2, next cycle of operation, which Kurchatov did not discuss at all, is shown here. It looks as if discharge were current and voltage are simply oscillating with no structure as was engendered by pinch effect in first cycle

The theory of processes taking place in completely ionized plasma indicates that at high field strengths H and high temperatures the transverse thermal conductivity coefficient is inversely proportional to H^2 and decreases by many orders of magnitude with respect to the value found in the absence of a magnetic field. However, under these conditions radiation losses must be considered.

The magnetic field required to provide the thermal insulation can be produced by passing a sufficiently intense current through the plasma. The current will also heat the plasma as a result of Joule losses and of the work of electrodynamic forces. These considerations were the basis for carrying out theoretical and experimental studies of the physical processes that occur in a plasma on passage of intense currents.

Theory of the Pinch Effect

We shall first examine the principal theoretical concepts that preceded the experimental work. When a current is passed through a plasma the latter should contract under the action of electrodynamic forces (attraction of parallel currents). An increase of plasma temperature should follow. If a contracted column of the plasma is detached from the vessel wall as a result of electrodynamic contraction ("pinch" effect) its temperature may be estimated from the condition that the pressure of the ionized gas is balanced by the electrodynamic forces.

A simple computation shows that in such quasi-stationary contraction processes the plasma temperature should be proportional to the square of the current. As is well

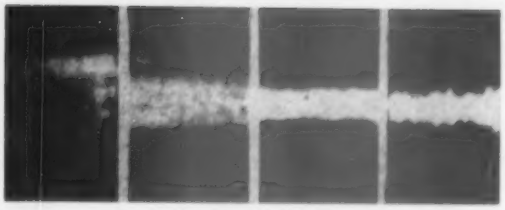

FIG. 4. Four successive frames taken at 0.5-μsec intervals as the discharge undergoes its first contraction. First kink in current oscillograms (Figs. 1–3) occurs at just this phase

FIG. 5. Time variation of a section of the deuterium discharge as photographed with a rotating mirror. Scale here is 1 μsec = 11 mm, based on photograph and caption in original article. Pressure was 10 mm Hg; maximum current was 1.2-million amp. T/4 = 9.5 μsec. Semispherical electrodes spaced 45 mm apart were used in 180-mm-diameter chamber

known, if the electrons and ions are in thermal equilibrium the plasma temperature can be expressed by the equation:†

$$T = I^2/4Nk$$

Here I is the current expressed in electromagnetic units, N is the number of particles of a given sign per centimeter length of discharge tube, and k is the Boltzmann constant, 1.38×10^{-16} erg/°C. Investigation of the conditions of thermal equilibrium showed that for $N \sim 10^{17}$ the electron and ion temperature should be practically identical. At appreciably lower values of N only the electron temperature will increase.

A contracted plasma column detached from the walls can exist only as long as the current is building up. If the current is constant the column will disintegrate and come in contact with the walls.

It is evident that a thermonuclear reaction with a constant yield over an appreciable period of time cannot be produced by passing a current through a plasma. In principle, it should be feasible to periodically heat the plasma and induce thermonuclear reactions in phase with the peak current.

Calculations of the expected thermonuclear effect led to the following result, which at first glance may seem paradoxical. It was found that during a single heating cycle the total number of elementary nuclear interactions pertaining to a given value of the peak current should be independent of the duration of this cycle. Thus, it seemed that it should be possible to excite very intense thermonuclear reactions by sending pulsed discharges of very short duration through deuterium if the current was sufficiently large. Theoretical calculations indicated that even a current of 300 kiloamp should be sufficient to produce an appreciable emission of neutrons of thermonuclear origin. At currents of several million amperes the emission should be very intense.

Such were the theoretical predictions that preceded the experimental work.

Gas-Discharge Experiments

Further development of concepts regarding the nature of the processes occurring in a plasma during the passage of an intense current was profoundly influenced by the new facts discovered during experimental investigation of powerful pulsed discharges. These results completely altered the landscape and colors of the picture created by the first spurts of theoretical effort.

Experimental investigation of intense pulsed discharges was carried out in a broad range of the parameters characterizing the initial discharge conditions.*

Discharges through hydrogen, deuterium, helium, argon, xenon, and gas mixtures (deuterium-helium, deuterium-argon, deuterium-xenon) of various relative content were studied. The measurements were carried out at gas pressures ranging from 0.005 mm Hg to 1 atmosphere. Most of the experiments were performed with straight discharge tubes. The length of the discharge gap varied from several centimeters up to 2 m and the diameter from 5 to 60 cm. The discharge was produced by a voltage of several tens of kilovolts. The peak current varied from 100 kiloamp up to 2×10^6 amperes, the rate of buildup of the current lying between 10^{10} amp/sec and 10^{13} amp/sec. The maximum instantaneous power released in the plasma in these experiments was as much as 40×10^6 kw.

Banks of high-voltage condensers were used to produce the discharges. The leads that carried the current from the condenser to the discharge gap were designed to keep the parasitic inductance of the electric circuit down to minimum since this factor restricted the magnitude of the current and its rate of growth. For a voltage of 50 kv and total capacity of the condenser bank of several hundred μf, the parasitic inductance of the circuit and switch was only 0.02–0.03 μh (in those cases when the current growth was maximal).

"The inductance of the Russian capacitors is impressively low for their capacity. Generally their experimental techniques seem advanced."—Heinz Fischer, Cambridge Research Center.

Oscillographic methods of measurement of the main parameters characterizing the state of the plasma during passage of a current were developed and these were used to study the intense pulsed discharges. Besides oscillography, ultra-high-speed moving-picture cameras (up to 2×10^6 frames/sec) were used as well as photography by aid of Kerr cells supplied with special electroexplosive types of shutters.

In addition to the discharge current and voltage, oscillograph records were also made of the intensity of separate spectral lines from the plasma, of the neutron and X-ray intensity, of the magnitude of pressure pulses measured with aid of piezoelectric elements, and also of the instantaneous magnitude of the magnetic and electric field strengths at various points within the plasma. The magnetic and electric fields were measured with small probes in the form of miniature coils, loops, or needle

† [See, for example, L. Spitzer, "Physics of Fully Ionized Gases," p. 42 (Interscience Publishers, Inc., New York, 1956).]

* In England, pulsed discharges in gases have recently been investigated by I. D. Craggs and his collaborators, S. W. Cousins and A. A. Ware, and others. [See also NU, Feb. '56, p. 42.]

electrodes of various shapes that could be placed at various points within the discharge vessel.

Behavior of High-Temperature Discharges

Space limitations do not permit me to give a detailed account of the numerous results obtained in this series of experiments, and I will therefore report only a small part of the available experimental material.

Of greatest interest is the first phase of the discharge during which the plasma current rises from zero to the peak value. In the experiments discussed here this phase lasted from 3 to 30 μsec. At the beginning of the discharge, after breakdown of the gas, a smooth increase of the current and voltage in the discharge gap takes place. After a certain period of time a sharp decrease of the voltage occurs. At the same time a more or less pronounced kink can be seen on the current oscillogram (see Fig. 1, which illustrates the general nature of time variation of the current and voltage; see also Figs. 2 and 3).

After the first drop the voltage began to rapidly increase and then sharply dropped again. This second voltage decrease was paralleled by appearance of a new kink on the current oscillogram. In some cases, three consecutive sharp changes in the otherwise smooth variation of the current and voltage were observed at the first stage of the discharge.

These characteristic features of high-current pulsed discharges are especially pronounced when the discharge takes place in gases of low atomic weight (hydrogen, deuterium, helium) and at low initial pressures.

When the rate of current buildup is of the order of 10^{11} amp/sec, the interval between breakdown of the gas and appearance of the first voltage drop comprises several microseconds.

This time interval is a regular function of the parameters characterizing the initial conditions of the discharge. For a given discharge-tube diameter it approximately varies as the fourth root of the gas mass per centimeter length of the discharge gap.

Inductive reactance is much larger than ohmic resistance in pulsed discharges in which the current increases at a high rate. Thus, by using current and voltage oscillograms one may find the time dependence of the inductance of the plasma column and hence determine how the radius of the column changes at various stages.

An analysis of this type shows that in all cases the very first stage of the process is featured by an increase of the inductance due to contraction of the plasma towards the discharge-tube axis. The speed of constriction of the plasma increases with the initial current build-up rate (that is, with the derivative dI/dt) and decreases with the gas density. At the moment when the kink on the current oscillogram appears and a sharp drop in the potential is observed, the inductance begins to decrease. This means that this moment corresponds to maximum contraction of the plasma filament. This situation is followed by a rapid expansion of the plasma filament. The appearance of several kinks on the current oscillogram signifies that consecutive contractions and expansions of the column take place.

These conclusions, which were obtained by analyzing current and voltage oscillograms, are confirmed by data obtained by applying ultra-high-speed cinemaphotography of pulsed discharges of tubes with transparent walls. On Fig. 4 are shown four successive frames of a moving picture of a pulsed discharge in deuterium at a pressure of 0.1 mm Hg and peak current of about 200 kiloamp. These pictures were taken at intervals of 0.5 μsec and refer to only a very small period of development of the process, which corresponds to the current and voltage break. The plasma-column minimum diameter corresponds exactly to this moment (the moving picture frames were phased with the current and voltage.)

Figure 5 was obtained by using a moving-picture camera for continuous photography. In this method a narrow slit perpendicular to the axis of the discharge tube subtends a small segment of the discharge gap whose image is swept across the film with a high speed. As a result, a continuous picture of variation of the diameter of a small segment of the plasma column was obtained on the film. The photograph shown here was obtained for a discharge in deuterium with a peak current of about 10^6 amperes. The initial gas pressure was 10 mm Hg. The moment of maximum contraction and the further development of the process are clearly visible.

Photographs of the contracting plasma column obtained with a Kerr cell are shown in Figs. 6 and 7.

Valuable data on the main physical processes occurring in intense pulsed discharges can be obtained by measuring magnetic and electric field strengths in the plasma. Magnetic-field measurements permit one to draw the following picture of current distribution in the plasma: Directly after breakdown, the current-conducting region is a thin cylindrical layer adjacent to the discharge-tube walls. The inner boundary of this layer at first slowly and then more rapidly moves towards the axis. After a certain interval of time the current fills the whole tube as

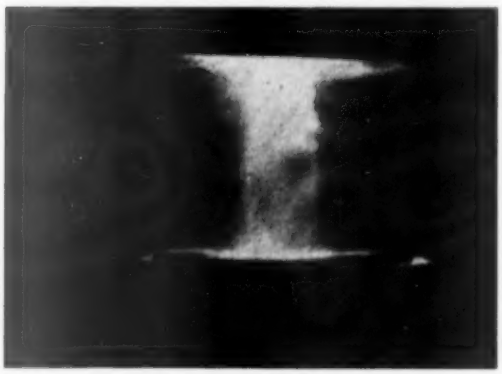

FIG. 6. Moment of contraction of discharge column as photographed in 0.2-μsec exposure with a Kerr cell. Initial pressure 1 mm. Distance between electrodes 45 mm, diameter of vessel 180 mm; hence side walls of vessel are outside of photograph

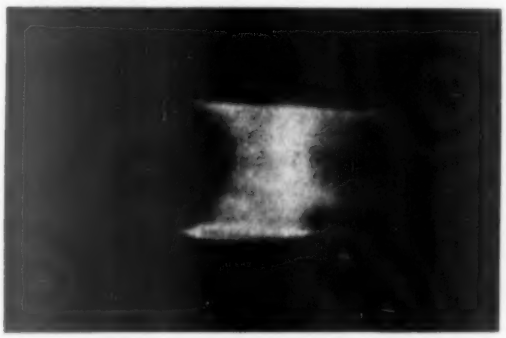

FIG. 7. Photograph of deuterium discharge made with Kerr cell 2.2 μsec after discharge began. Exposure was 0.2 μsec. Initial pressure was 1 mm Hg; distance between electrodes, 40 mm

a result of movement of the inner current boundary. The moment at which the current reaches the axis practically coincides with the time of appearance of the first kink on the oscillogram.

The current density near the discharge axis at this time exceeds the mean current density over the cross section of the tube by several dozens of times. On subsequent expansions and constrictions the current density remains very high in a central region of several centimeters in diameter although fluctuations are appreciable.

The current density distribution over the cross section of the discharge tube at various periods of time is shown schematically in Fig. 8. The current density distribution at the very first stage of the discharge is shown in the left figure. The second one refers to the moment when the current was moving towards the axis. The distribution after the first contraction of the plasma column is illustrated in the right figure. An interesting feature of this stage of the process is that in a certain zone of the discharge the current reverses its direction.

The velocity of the ionized gas is the quantity that directly characterizes the dynamics of a pulsed discharge.

In a plasma of sufficiently high conductivity this velocity is determined by the ratio between the longitudinal electric field strength E and the magnetic field strength H

$$v = cE/H$$

Measurements of E and H indicate that in a pulsed discharge with rapid growth of current the radial velocity of the plasma may be very high. In the experiments described here the maximal velocity during contraction and expansion of the plasma column in rarefied gases was found to reach hundreds of kilometers per second. This signifies that the kinetic energy of the drift of the plasma ions is of the order of several hundred electron volts.

Neutron Production

One of the most interesting effects observed in intense pulsed discharge in light gases is the appearance of penetrating radiations. In 1952, soon after experiments with pulsed discharges were started, it was found that at sufficiently high currents the discharge in deuterium becomes a source of neutrons.

A comparison of chronologies makes it seem that the Russian and U. S. efforts got out of the talking stage at about the same time. According to press releases of October 3, 1955 the AEC project began in 1951. The first definitive experimental program at Los Alamos got underway in January, 1952, followed by Princeton in June, 1952 and Livermore somewhat later.

The first experiments performed with the aim of studying this phenomenon showed that neutrons appear when the peak discharge current is 400–500 kiloamp and the initial deuterium pressure is about 0.1 mm Hg. The neutron emission was observed in a relatively narrow pressure range and its intensity rapidly increased with increase of the applied voltage, i.e., with increase of the peak current. In these first experiments the radioactivity induced in a silver target embedded in a paraffin block placed near the discharge tube served as the neutron detector. A possible explanation of this phenomenon was that the neutron emission resulted exclusively from collisions between the accelerated deuterons and deuterium adsorbed by the electrodes on tube walls; however, control experiments did not confirm this explanation.

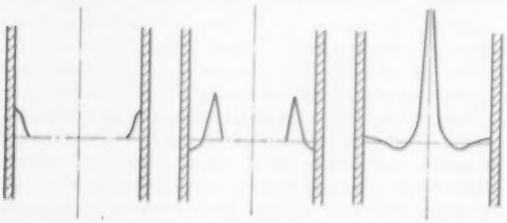

FIG. 8. Distribution of current density across the discharge tube at the very first stage of the discharge, then as the current moves towards the axis, and finally after the first contraction of the discharge column. Note that in certain zones current reverses its direction

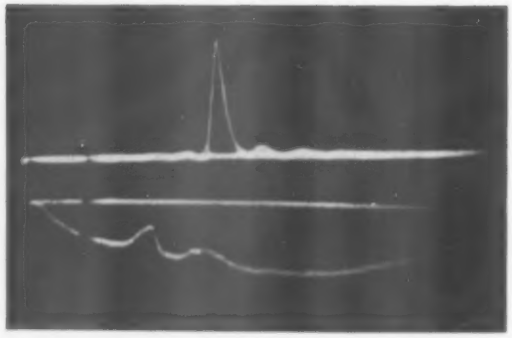

FIG. 9. Neutron production in deuterium discharge as observed with a scintillation counter. Applied voltage was 40 kv, initial pressure 0.05 mm Hg. Neutrons are produced in sharp pulse during second contraction of discharge column. Experiments like these demonstrate that neutrons are not result of quasi-stationary heating of plasma (which would be truly thermonuclear) but rather as result of an acceleration mechanism that makes some ions sufficiently energetic to fuse on colliding

"The fact that silver irradiation was used as a detector implies that the neutron flux was at least of the order of 10^6 n/cm²/sec. It would take that flux during a 2-μsec burst to produce 1 cps in a 10-gm foil."—R. Stephenson, New York University.

At the early stages of investigation it was quite natural to assume that the neutrons resulted from thermonuclear reactions in the plasma heated to a high temperature. This was exactly what was expected from the beginning and the fact that the effect was detected under conditions that completely corresponded to the *a priori* theoretical predictions seemed to speak in favour of this viewpoint. The behavior of the neutron radiation (its dependence on pressure and current) observed in the first experiments qualitatively concorded with the assumption that the phenomenon was due to thermonuclear mechanism.

However, very soon serious doubt concerning the correctness of this assumption began to appear. This happened after it was found that neutrons can be observed at comparatively small discharge currents, of the order of 150 kiloamp. According to the initial calculations the intensity of the thermonuclear reaction at currents of 150 kiloamp should practically be zero.

In subsequent experiments the neutrons were recorded with scintillation counter fed to an oscillograph. This technique made it possible to find the relation between the discharge properties and the moment of appearance of neutrons. It was found that the neutrons were always emitted when the second kink appeared on the current oscillogram, i.e., at the moment when the plasma was subjected to the second contraction (Fig. 9). No neutrons were produced during the first contraction.

Two Scientists Say: "Honest talk" . . . "We must declassify"

D. J. Hughes, Brookhaven National Laboratory—

Kurchatov's speech is a typical high-level technical talk, honest and straightforward, and not an attempt to convey the impression of releasing information without really doing so. Many detailed numbers are given in connection with the experiments described and this detail would not be necessary if the desire were simply to create an impression. The talk was very much like those given by the Russians at the Geneva meeting last August.

It is interesting that Kurchatov gave another talk at Harwell, on liquid-moderated power reactors, and this talk was again a straightforward one with lots of technical detail. The reactor talk was distributed as a printed pamphlet in just the same way as the thermonuclear talk, which further strengthens the opinion that they both contain open release of real information.

It seems very important to me to note that the thermonuclear work represents the first time that the Russians have released information ahead of us.

It goes without saying that in my opinion the controlled thermonuclear field should be opened up completely in this country, and at once, so that progress will be accelerated.

J. G. Beckerley, Schlumberger Well Surveying Corp. (Former director of classification of AEC.)—

The Kurchatov lecture at Harwell was not sensational in substance, but simply an interesting, semiquantitative report of extensive fundamental studies of gas discharge phenomena. The circumstances of the lecture were sensational. At Harwell, scientists of a nominally free nation were given a public lecture by a representative of a totalitarian nation on fusion for peace.

Of itself, the Kurchatov lecture should not be considered an argument for removal of secrecy from thermonuclear reactor projects. There are many good reasons for declassification quite independent of what the USSR does or says. Continuation of secrecy means, in this country, a continuation of the present inadequate efforts. The AEC must realize that this "truly frontier research project" must be completely unclassified if we expect to maintain our technical leadership.

It is to be hoped that the Kurchatov lecture will stimulate public and private debate on the wisdom of continuing secrecy on controlled thermonuclear reactors. Scientists should realize that the AEC's information policy on fusion power represents a radical departure from the traditional openness of nonweapons basic research in peacetime.

The neutrons were always emitted as short pulses with a steep front. The rise time of the pulses was several tenths of microseconds. The chief results of the oscillographic investigations were not consistent with the initial assumption that the neutron emission is the result of quasi-stationary heating of the plasma during which the temperature increases proportionally to the square of the current.

Further investigation yielded new interesting facts pertaining to the plasma neutron radiation. In particular, it was established that in specially designed discharge tubes the neutrons could appear at fairly high deuterium densities, as much as several tens of millimeters of initial pressure. This fact signified that the neutron emission was certainly not a trivial effect.

X-rays. It was found that not only neutrons but hard X-rays as well were produced in pulsed discharges. Penetrating X-rays were found when large currents were passed through hydrogen, deuterium and helium. The radiation produced by discharges in deuterium always consisted of short spurts. The pulses due to the neutrons and X-ray quanta always appeared simultaneously on the oscillograms. The energy of the X-ray quanta produced in pulsed electrical processes in hydrogen and deuterium reached 300–400 kev. It is noteworthy that at the time of emission of such high-energy quanta the voltage applied to the discharge tube was only about 10 kv.

Understanding the Experiments

Theoretical analysis of the complex phenomena that occur in the plasma of a pulsed discharge oscillating under the action of electrodynamic forces is still at such a stage that quite a number of facts remain to be explained. However, the general picture of the process is gradually becoming clear and some of the peculiarities of the phenomenon seem to have been sufficiently elucidated.

It is now clear that contraction and expansion of the plasma are not quasi-stationary processes characterized by equilibrium between the external and internal pressures.

In the equations describing the dynamics of a pulsed discharge the main term is that which accounts for momentum changes in the ionized gas due to magnetic pressure. Thus, the kinetic energy of the ordered motion should at some stages of the process greatly exceed the thermal energy concentrated in the plasma.

> ***"A very important point, but one somewhat difficult to get from the text, is that the neutrons detected were not true thermonuclear neutrons and hence not of importance for a real self-sustained thermonuclear reaction. It is an 'ordered motion' that produces the neutrons, the energy coming from 'acceleration by a high electronic field that may exceed the instantaneous voltage applied to the discharge tube by many times.' This ordered motion is not temperature agitation, in other words does not imply that the high temperature needed to sustain the reaction has been attained."—D. J. Hughes, Brookhaven National Laboratory.***

At the initial stage of the discharge the internal pressure in the plasma is very small; thus the electrodynamic forces produce acceleration along the radius towards the

Continued on p. 123

Transient Experiments with the SPERT-1 Reactor

Progress, test methods, and data in safety tests on heterogeneous reactors using enriched fuel and water as moderator and reflector indicate the general usefulness of testing reactor types for safety characteristics. But they also emphasize the need for care when extrapolating data on detailed behavior

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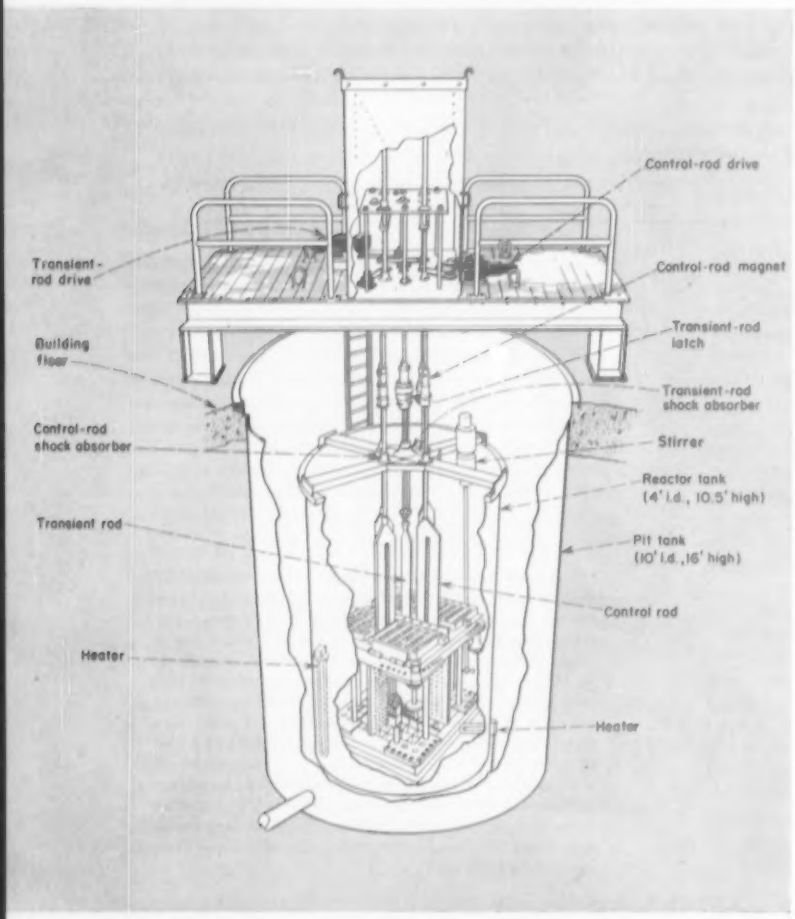


FIG. 1. SPERT-1 reactor tank is supported on short legs from bottom of shield tank. Support grids above and below fuel assemblies clamp them in place. For operation, water level in reactor tank is several feet above core top

A TRANSITION IS UNDERWAY in the reactor scene that brings new emphasis to problems of reactor safety. The large number of proposed reactors increases the probability of an accident and the move from rural to urban areas increases the penalty of such an accident.

Since it is likely that a serious accident would set back the nuclear-power industry for many years, it must be avoided by maintaining the admirable record of safety of the preceding years.

Safety Test Programs

The U. S. Atomic Energy Commission is sponsoring an intensified reactor-safety program (*1*). Prior work by the Argonne National Laboratory in the Borax tests (*2*) was the first primarily directed to these problems.

The Argonne experiments focused attention on the underlying problems of reactor transient behavior and served as a starting point for the continuation and extension of experimental studies of this kind. As a major part of this activity, Phillips Petroleum Company is operating the SPERT (Special Power Excursion Reactor Tests) facility at the National Reactor Testing Station in Idaho.

The role of the SPERT project in the program has been defined as a heterogeneous-reactor test facility for testing safety characteristics of five reactor classes (*1*). The test program for the enriched-fuel, water-reflected and -moderated reactors described as

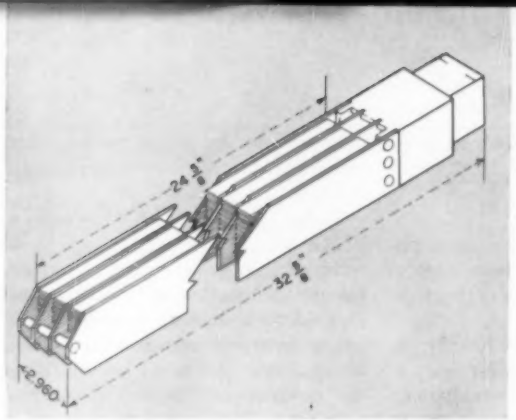


FIG. 2. SPERT-1 fuel assemblies are of Al-clad Al-U-alloy plates of 0.060-in. total thickness separated by 0.117-in. water channels

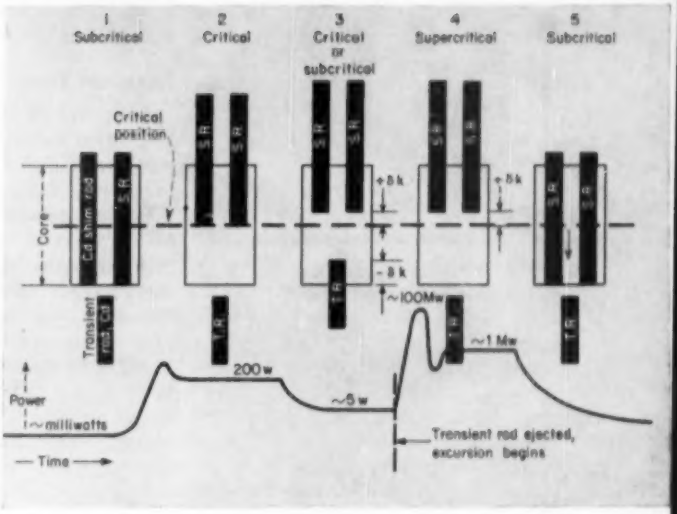


FIG. 3. Transient test sequence

SPERT-1, -2 and -3 will be considered further here with the discussion centering around the nature of the efforts to date and experimental procedures.

SPERT-I Reactor

Figure 1 is a cutaway of the SPERT-1 reactor. The reactor pit is covered by an uninsulated galvanized-iron building. Just outside the pit building is an earth-covered bunker that houses the control relays for power equipment in the pit building, and the electronic equipment required by the transient and control instrumentation.

Control rods. Four Cd blade-type control rods function as a group for reactor operation; a similar rod is used to initiate excursions.

The control-rod group has a continuously variable speed adjustment on withdrawals up to 10 in./min, which is about 0.1% (or 13¢/sec) in reactivity. The magnetic clutches are decoupled from their individual driveshafts by interrupting magnet current and by small air pistons that speed insertion and effectively release all rods simultaneously.

The central rod, which in its normal position of rest has the cadmium portion outside and below the reactor, is lifted upward to bring poison into the reactor. Transients are initiated by releasing the suspended rod and driving it downward out of the reactor to remove the poison. The coupling between this rod and its drive is mechanical. The release is effected by the action of small air pistons and an acceleration of about 10*g* is supplied by another air cylinder. The travel time varies between 80 and 120 msec depending on the release position, which is determined by the amount of reactivity to be injected.

Fuel assemblies. Figure 2 shows a cutaway view of a fuel assembly. Although it was desired to keep the reactor system similar to BORAX for ease of data comparison, the fuel assemblies had to be strengthened because part of SPERT-1's testing program involved tests in the period region between the fastest nondestructive test and the destructive test performed by ANL in the BORAX experiments. The stiffening members, which effectively separate the assembly into three subassemblies, decreased water-channel width by a factor of three.

Relief holes are provided in the square end boxes on the bottom end of the assemblies. These and the bottom-grid design provide for some coupling of the water channels between assemblies with other channels. The corresponding channel was blocked in the Borax experiments. These changes should be most apparent in those factors that are greatly influenced by the hydrodynamical system of the nuclear-thermal-hydrodynamical complex. Presumably, the thermal characteristics of the plates were left unchanged. The lattice used for most of the transient tests consisted of 28 assemblies.

Nuclear characteristics. Experimentally determined nuclear characteristics of the core are shown in the table.

Site. Tests that might lead to the violent self-destruction of the test reactor were viewed as a part of the program.

The site selected is in the National Reactor Testing Station, where destructive experiments can be carried on with relative ease and without hazard to the public. However, some isolation of the test site is required within the National Reactor Testing Station so as to prevent interference with other NRTS installations. There-

Cover—SPERT-1 Transient Test

Camera looking down into the water-filled core tank shows the reactor self-lighted by the "blue glow" resulting from intense radiation emitted during a transient in which the power rose from 2 watts to 510 Mw in 0.75 sec. Reactor period was 13 msec; energy release was 16 Mw-sec.

Silhouetted above the tank are control mechanisms and their supports. Projecting down into the tank can be seen two of the four T-shaped rods carrying cadmium control "blades" that are inserted or withdrawn to control the reactor. In tank center is a central control rod used to initiate the sudden rise in power. Network of squares is the upper grid, which helps support the fuel (visible as the dark central area outlined by the brightest part of the glow).

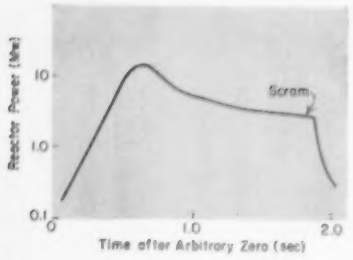


FIG. 4. SPERT-1 transient test, 100-msec period, core water initially 18° C

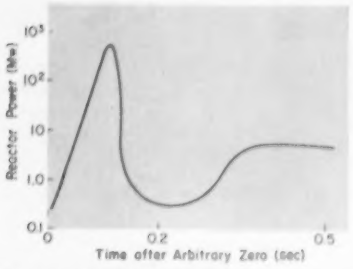


FIG. 5. SPERT-1 transient test, 13-msec period, core water initially 18° C

fore, the distance from the SPERT site to the nearest major roads or installations within the NRTS area is three miles, which is a working compromise between economy and protection by isolation. Within the SPERT facility, protection for the operating personnel is provided by remote operation of the reactor from a control center at least one-half mile away.

Transient Tests

A description of a typical transient test serves to explain the usual experimental procedure and a few of the steps in handling data.

Typical procedure. Ordinarily, a test or series of tests requires lengthy preparations in the form of installation, checking, and calibration of equipment. Occasionally this also includes complete unloading and loading of the core. Handling of the radioactive fuel assemblies during this operation has presented no serious problem, but it does require a cooling period of several days after most tests.

Just prior to each test, personnel are withdrawn to the control center, where the road to the pit is blocked by a security guard. A final check is made on the locations of individuals by a "nose count" before rod withdrawal begins. This procedure also is followed in cases not involving transient tests.

The initial experimental step is to determine the control bank's critical position, which varies with changes in such things as the water purity or temperature. The critical position is measured at a power level of about 200 watts with the poison section of the transient rod entirely out of the reactor. The system is made subcritical and its power reduced by pulling the transient rod upward into the core in preparation for starting a transient.

During the decay of the power to a level of several watts, the control bank is withdrawn to its position for the transient. Ejection of the transient rod will then make the reactor supercritical by the desired amount. When the operator decides to proceed with the transient tests, he arms the center-rod ejection system. At any time thereafter the transient sequence can be started by activating the transient sequence timer. According to a preset schedule, the timer starts cameras, recording equipment, etc., initiates the ejection of the center rod, and at the desired time scrams the control rods and shuts off equipment. Tests can be run as frequently as once every 10 minutes, but the average time is about an hour per test. (See Fig. 3.)

Meters in the control room indicate the gamma-ray level near the reactor. Thus, it is not necessary to approach the area to determine when safe entry can be made. Personnel working in the reactor area are always equipped with portable health physics instruments. This is especially important immediately after reactor operation because the radiation levels vary enormously within the area. For example, permissible working times may be as short as minutes at the edge of the pit.

Testing Safety of Enriched-U Water-Moderated Heterogeneous Reactors

SPERT-1; for testing effects of core variables. *Since the start of the project in October, 1954, the major effort of the SPERT group has been the design, construction, and initial operation of SPERT-1, the first step in the heterogeneous-reactor test program. It is a nonpressurized water-moderated and -reflected reactor with MTR-type enriched fuel. It will be used to investigate how transient behavior is influenced by such parameters as void coefficient and to determine safe upper operating limits in regard to permissible excess reactivity, minimum shutdown power level, etc.*

All the desired information cannot be obtained with this simple system. Hence, concurrently with the work on SPERT-1 an appropriate share of effort was devoted to considerations of the tests and facilities required for the long-range program. Construction of two additional reactors as a part of this extended program will begin this year. Conceptual designs for both reactors have been completed.

SPERT-2; for testing effects of reflector and core variables. *The smaller of the latter two reactors is designated SPERT-2. It will be a low-pressure (300 psi) low-temperature (400° F) system whose primary function will be the study of how various types of moderators and reflectors influence reactor transient behavior and safety. Initial studies with this facility will compare moderator-reflector systems using light and heavy water. The first tests will probably use aluminum-plate assemblies.*

The vessel has been designed to facilitate changes in core and reflector configurations so that experiments can be conducted using graphite and beryllium reflectors also. Certain engineering and safety studies requiring short-time power operation can also be undertaken. The wide range of prompt-neutron lifetimes available with this flexibility will permit investigation of the influence of lifetime on transient behavior, which is expected to be strong for reactivities above prompt critical. Peak power, transient pressure, and energy release are expected to vary with lifetime.

SPERT-3; for testing effects of conditions of high-power reactors. *The design study has been completed for SPERT-3, a high-pressure high-temperature facility that will provide for basic transient studies and safety and engineering studies of particular importance to the advancement of water-cooled and -moderated power-reactor technology. Pressures up to 2,500 psi, temperatures up to 670° F, and coolant flows up to 20,000 gpm will be provided. Heat removal also will be provided to permit short-time operation at power. Because of the rapidly developing U. S. power-reactor program, the work on SPERT-3 will take precedence over SPERT-2.*

Characteristics of SPERT-1 Core*

Critical mass (23 fuel assemblies, 18° C)	3.86 kg U^{235}
Excess reactivity with 28 fuel assemblies	4% k_{eff}
Prompt neutron lifetime	50 ± 5 μsec
Reactivity loss from 20° C to 95° C (boiling)	1.05% k_{eff}
Temperature coefficient at 20° C	-0.9×10^{-2}% Δk_{eff}/°C
Temperature coefficient at 95° C (boiling)	-2.0×10^{-2}% Δk_{eff}/°C
Average void coefficient for core	-3.5×10^{-4}% Δk_{eff}/cm³ void
Maximum void coefficient (center of core)	-7.2×10^{-4}% Δk_{eff}/cm³ void
Reflector void coefficient (adjacent to core)	-0.69×10^{-4}% Δk_{eff}/cm³ void

* Volume of water in the core is 54×10^3 cm³.

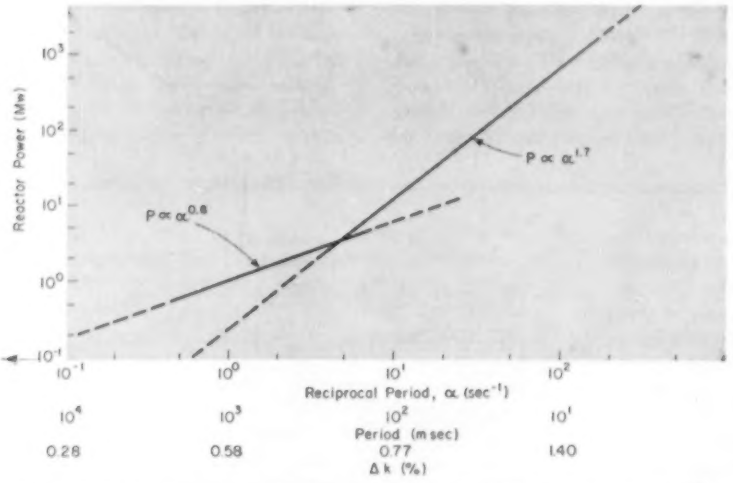


FIG. 6. How peak power varies with reactor period. Initial water temp. ≈20° C

Ordinarily, the pit building can be re-entered 10–20 min after the test.

Usually the oscillograph charts are processed immediately after a test and are available for an initial measurement of the periods, peak power and peak temperature within 10 min. At a later time a Benson-Lehner data handling system is used to read and replot in real units traces such as appear in Figs. 4 and 5.

Remote operation has advantages. It might seem that remote operation of the reactor imposes discouragingly arduous working conditions on the experimenter. Actually, as is often the case, the obvious disadvantage tends to obscure factors that can be used to considerable advantage. One of these is the improvement in accessibility of core and tank by the elimination or reduction of costly shielding. In addition, major economies and simplifications can be made in control instrumentation and reactor operation without lowering safety standards. With SPERT-1 remote operation has been only a minor inconvenience.

Typical characteristics. Figures 4 and 5 show some of the characteristics of typical reactor transients. The first part of the tests, which covers the power region from 2 watts to about 100 kw, is not shown. The reactor temperature initially was about 18° C. In both cases the power rise was essentially exponential for the last several decades. Most of the shutdown effects appear in the neighborhood of the power peak. In the 100-msec case, the damping of the system returns the power gradually to a stable value without any undershoots in the period of the observation. The 13-msec case exhibits a large undershoot, but the second rise in power also appears strongly damped and does not show additional oscillation.

Comparison of the two transients also shows a definite change in the rate at which the shutdown takes place relative to the initial period. The long-period run has a rising slope steeper than the shutdown slope. In contrast, the slope on the shutdown side of the short-period transient is greater than on the rising side. Stated another way, plots of power versus reactor period as the unit of time show shape changes after the power peak for different initial reactor periods.

SPERT-1 Experiments

Measurements made in the experimental program included: static measurements, transient tests for orientation and an 18° C water-temperature series, ramp-rate studies, and service operation as a pulsed source.

Static measurements. These consisted of nontransient tests that included the usual measurements concerned with reactor properties (rod calibration, flux maps, etc.). The work on void effects is of special interest. Several sets of measurements were made to determine reactivity loss as a function of the quantity of distributed voids in the core, and the relative effectiveness of voids as a function of position in the core. The voids were made by stuffing sausage casings into the water channels of the fuel assemblies and then inflating them.

The average value of 0.2% Δk_{eff} per percent of voids in the water obtained for uniformly distributed voids in SPERT-1 does not differ greatly from the calculated average value of 0.24% for BORAX-1 (2). However, the range of values of the void coefficient in the core is sufficiently large so that actual void distribution is very important in determining the effective average value to be used during a transient. The void coefficient may differ significantly in the two reactors.

Transient tests. The second group of tests consisted of a series of orientation runs in which reactor initial temperature was varied from ambient to boiling; periods were 100 to 10 msec.

Following this, a series of subcooled measurements was made with the reactor temperature initially at 18° C. The reactor periods covered the range between 2.5 sec and 7 msec. Shorter-period transients at this temperature probably will cause significant core damage; they are being deferred until more nondamaging tests are completed. These will include similar series of tests at higher temperatures.

From a series such as this it is possible to go beyond the previous discussions of the features of individual transients and study a single characteristic of a number of tests. For example, Fig. 6 shows the variation of peak

power with initial period. The upper portion of the power curve includes the period region covered by BORAX-1 and has essentially the same slope.

The region of interest is not confined to the initial burst, but includes the subsequent behavior as well. Secondary peaks may be present or the reactor power may drift smoothly down to an essentially stable value determined by the steam compensation of excess reactivity. Behavior in this region helps in understanding mechanisms of behavior during the initial transient and in determining the long-time stability.

SPERT-1 behavior on long-time studies (several seconds duration) is markedly different from Borax-1. Figure 7 shows a plot of reactor power for BORAX-1 and SPERT-1 following a 14-msec excursion. SPERT-1 appears to be more strongly damped. Factors that could contribute to this are differances in (a) fuel-assembly construction, (b) effective void coefficients, or (c) reflector-tank environment.

Ramp-rate studies. Some runs were also made in which the input of reactivity was not a step-function as in the previous transient tests but instead was a linear function of time. These ramp-rate tests used rates of addition of reactivity comparable with or somewhat greater than those normally used in reactor startups but were considerably below the step-rates for transient tests.

The experiment also differed somewhat from the previously described test. Tests were started with the reactor critical or very nearly so, at the desired power level and the water temperature at 20° C. For runs with a low initial power it was necessary to remove the startup neutron source. Reactivity was then added to the system by withdrawal of the control rods at a fixed rate rather than by moving the transient rod, which was not used.

The fastest rate at which reactivity could be introduced in this manner was 10 in./min for the bank, or 0.1% $\Delta k/k$/sec (13¢/sec) in reactivity. In one such test, control-rod withdrawal was started with the reactor critical at a power level of several watts and continued for 17 sec during which time a total of 1.4% reactivity was added. The minimum period resulting from this was about 80 msec. The period resulting from a step input of this

SPERT Instrumentation—Better Detectors Needed

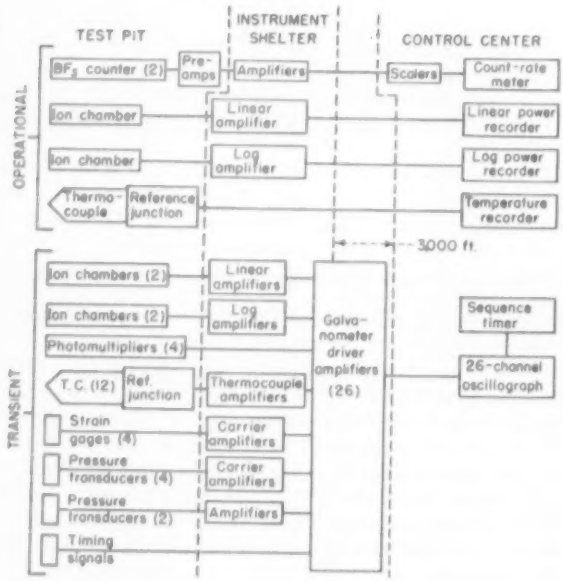
Instrumentation for SPERT-1 can be divided into two more or less separate systems—reactor control and transient instrumentation.

Control instruments. *The control system includes the basic elements found in most reactors; but it is distinguished primarily by its relative freedom from operational restrictions and protective devices. For example, there are no period or power-level trips; shutdown is achieved either by the self-regulating characteristics of the reactor or by a programmed shim-rod scram. Deliberate omission of these instruments has been coupled with the firm policy that all reactor operations are treated as potentially destructive tests that must be conducted remotely. This is viewed as a simpler and basically safer procedure than the intermittent inclusion of protective devices.*

For safety reasons, all reactor controls and most service functions can be operated solely from the control room. For example, remote controls are provided for draining and filling the shield or reactor tanks, and heating or stirring the reactor water. A television system provides for visual inspection of the area and the core. For operational purposes, neutron detectors just outside the shield tank indicate reactor power over the range from 5×10^{-3} watts to 3×10^{7} watts.

Transient instruments. *Detectors for the transient instruments are located around the reactor room, within the shield tank, on the reactor tank, and within the reactor core. Information of three kinds is normally obtained: powers, temperatures, and pressures. The amplifiers for the various detectors are located in the instrument bunker and are designed to produce a 1-volt output at the full range of the detector. This permits using standardized low-impedance amplifiers for driving high-speed galvanometers through the 3,000-ft coaxial cables connecting instrument bunker and control room.*

Transient signals are recorded on two 26-channel Consolidated Engineering Corporation oscillographs at the control center. Transient response of the combined electronic-



galvanometer system is such that a 1-msec period can be followed without distortion. The frequency response required of this system is greater than indicated by the rising period on a transient because on short-period transients the shutdown occurs much more rapidly than the power rise; this is important in interpreting shutdown mechanisms.

To obtain detailed information on the reactor transient behavior, physical measurements at several points within the core are essential. But limitations imposed by ambient conditions in the core and by nonperturbation requirements frequently necessitate use of detectors outside the core.

Radiation detectors. *The reactor power can be determined by neutron detectors external to the reactor vessel as long as the neutron-leakage fraction remains constant. However, the self-regulation of the reactor is accomplished through increase in neutron leakage, so the external flux is*

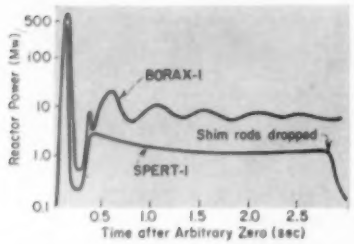


FIG. 7. Reactor power for BORAX-1 and SPERT-1 after 14-msec-period excursion. Initial water temp. ≈20° C

amount of reactivity would be about 9 msec. Initial power was also varied between 50 μw and 10 kw in another series. Tests were also conducted using a ramp rate of 0.01% $\Delta k/k$/sec.

Pulsed source. The reactor has also been used as a service for various tests conducted by groups from other laboratories. The excursions provided a pulsed source with known period.

Conclusions

The initial objectives of the SPERT program have been met. The results reveal two important features of the BORAX-1:SPERT-1 combination: (a) gross behavior of the two systems is similar, which demonstrates the usefulness of testing reactor types for evaluating hazards; (b) detailed behavior shows marked differences that emphasize the dangers of extrapolation and the need for a well-established point of reference for the determination of the importance of various parameters affecting the kinetic behavior. The SPERT program is intended to provide such a reference point.

* * *

On questions of major importance, the SPERT staff has had the benefit of the advice and assistance of representatives from most of the major AEC installations and from the Division of Reactor Development. The counsel of the Argonne National Laboratory was of special value in planning the instrumentation. C. F. Leyse (now at Internuclear Company) had a major part in the engineering aspects of the work reported herein. During the Summer of 1955, Prof. M. J. Jakobson, Montana State University, gave valuable assistance in the early stages of operation, especially in connection with void-effect measurements.

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2. J. R. Dietrich, *et al.* Experimental determinations of the self-regulation and safety of operating water-moderated reactors (Paper 481, U. N. International Conference on Peaceful Uses of Atomic Energy, Geneva, 1955)

not truly proportional to the reactor fission rate. For this reason, several external detectors that depend in a different way upon reactor power have been employed. These include boron ion chambers for slow neutrons, fast-neutron scintillators, gamma-ray scintillators, and a collimator-photomultiplier for observing Cerenkov radiation from the moderator.

All of these devices depend in some way on the moderator density but each measurement should be affected to a different degree for a given density change. The records from these devices have been examined for systematic variations in the vicinity of the transient peaks. It appears that the effects of moderator-density changes do not seriously perturb the measurements (i.e., of the order of 10% deviation from linearity or less for subcooled runs). Inpile fission-rate detectors are being developed to provide more detailed data.

Pressure detectors. *Commercial pressure transducers of three basic types—strain gage, variable reluctance, and variable capacitance—have been tried in the reactor vessel. These transducers are too large to permit direct insertion between the fuel plates and therefore have been restricted to positions outside the core proper. Measurements at the vessel wall are straightforward and valuable in assessing possible damage to the vessel itself. Transducers mounted in the lower end-boxes of the fuel assemblies give a better picture of the transient-pressure peaks. However, it is not possible to distinguish between static head and impact head with this arrangement; also, the pressures are averages of the effects in the many water channels in an assembly.*

Probes have been extended into the assemblies up to the reactor centerline. These were provided with static openings of approved design but the conditions of laminar flow for which these designs were intended are by no means assured in the water channels. The problem is further complicated by the evolution of dissolved and radiolytic gases inside the probe; these result in loss of frequency response in the coupling-tube system so that a water purge is necessary between tests.

All of these devices suffer in some degree from nuclear heating effects, slow response when immersed in water, or inadequate overload capabilities.

Temperature detectors. *The most troublesome detectors thus far have been the thermocouples for fuel-plate temperature measurements. The difficulty appears to be primarily a mechanical one resulting from the rapid differential expansion between the fuel plate and the thermocouple wires. Even spot and stud welds that were stronger than the thermocouple leads themselves failed under transient conditions. This difficulty has been overcome by peening the thermocouple wires into the fuel-plate surface.*

Although satisfactory from a mechanical standpoint these thermocouples leave something to be desired as detectors. The use of fairly large wire (0.010 in.) in a peened joint introduces uncertainties as to the exact location of the effective thermojunction; furthermore, it results in some loss in frequency response. Work is continuing on other methods for thermocouple construction, principally along the lines of evaporated layers. In the meantime, good comparative data are available between transients of different periods.

Photographic studies. *Both external and inpile photographic studies of reactor behavior have been undertaken. The external photographs consist primarily of moderate-speed (128 frames/sec) color movies of the reactor core. These pictures give considerable information on the motion of the water surface in relation to the reactor flash, relative violence of the water expulsion for boiling and subcooled runs, rod behavior, etc. A few high-speed (1,000 frames/sec) black and white movies have also been made to permit greater time resolution.*

Motion pictures of the moderator inside the core have been made by looking directly through the reactor vessel wall into a fuel assembly with a hole through the side plate. The gross behavior such as void appearance, two-phase flow and convection currents can be seen readily but the resolution achieved thus far is inadequate to permit quantitative determinations of void concentration, velocity, etc., as a function of time.

Better detectors needed. *The current need in instrumentation is in detector development rather than in the transmission and recording of the data. The detector problem will be even more acute in the SPERT-2 and -3 reactors.*

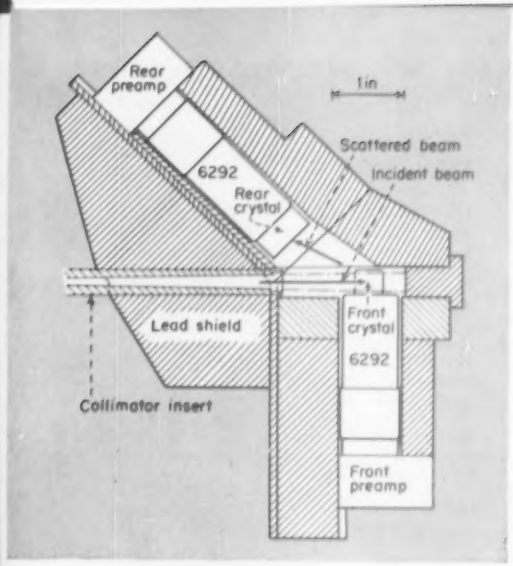

FIG. 1. Compton-spectrometer detecting head

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San Francisco, California

Fast Compton Scintillation Spectrometer

This spectrometer measures gamma-ray energies in terms of the energy of Compton-recoil electrons in coincidence with their associated gamma-rays Compton-scattered at 150 deg. Energy range is ~0.2–1.0 Mev. Resolution is 7.7% at 1 Mev. Efficiency is low, $\sim 10^{-3}$

A COMPTON GAMMA-RAY spectrometer* has been developed to analyze the spectra of gamma-rays emerging from slabs of shielding.

An ideal spectrometer records each gamma ray within a given solid angle and uniquely specifies its energy without limitations as to energy range or counting rate.

A practical gamma-ray spectrometer falls far short of these ideals; but by limiting the energy range and counting rate, usable gamma-ray spectra can be obtained. Due to the multiplicity of interactions of monoenergetic gamma rays with a gamma-ray detector (*1*), a unique energy response is most difficult to realize. The Compton spectrometer discussed here achieves such a unique energy response to a useful degree.

Principle of Operation

Gamma rays entering the collimating aperture of the Compton spectrometer (Fig. 1) strike the primary NaI(Tl) crystal. A certain fraction of these gamma rays are Compton scattered at an angle that allows the scattered gamma ray to enter the coincident crystal. The Compton recoil electron causes a scintillation in the primary crystal and a pulse from its photomultiplier. If the coincidence crystal absorbs all or part of the energy of the scattered quantum, its photomultiplier will put out a pulse simultaneously with the primary photomultiplier.

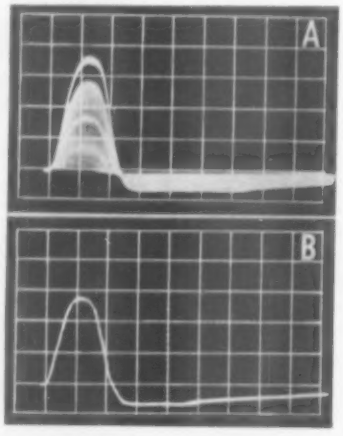

FIG. 3. (a) Primary-crystal pulse-height spectrum for Zn^{65} (1.112 Mev) as presented to the pulse-height analyzer. (b) Pulse height spectrum recorded by pulse-height analyzer for Zn^{65} when gated by back-crystal coincidences

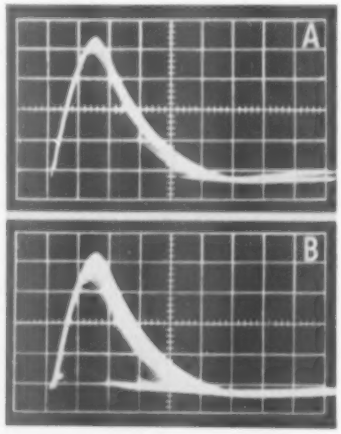

FIG. 4. (a) Amplified-coincidence-pulse spectrum for Zn^{65}. Horizontal scale is 1 μsec/div; vertical is 20 volts/div. (b) Same spectrum for Cs^{137}; note that coincidence-pulse height is independent of energy

* Hofstadter and McIntyre (*2*) enunciated the use of the Compton scattering process in NaI(Tl) detectors to measure gamma-ray energies. Maienschein (*3*) and Whyte (*4*) constructed improved Compton spectrometers.

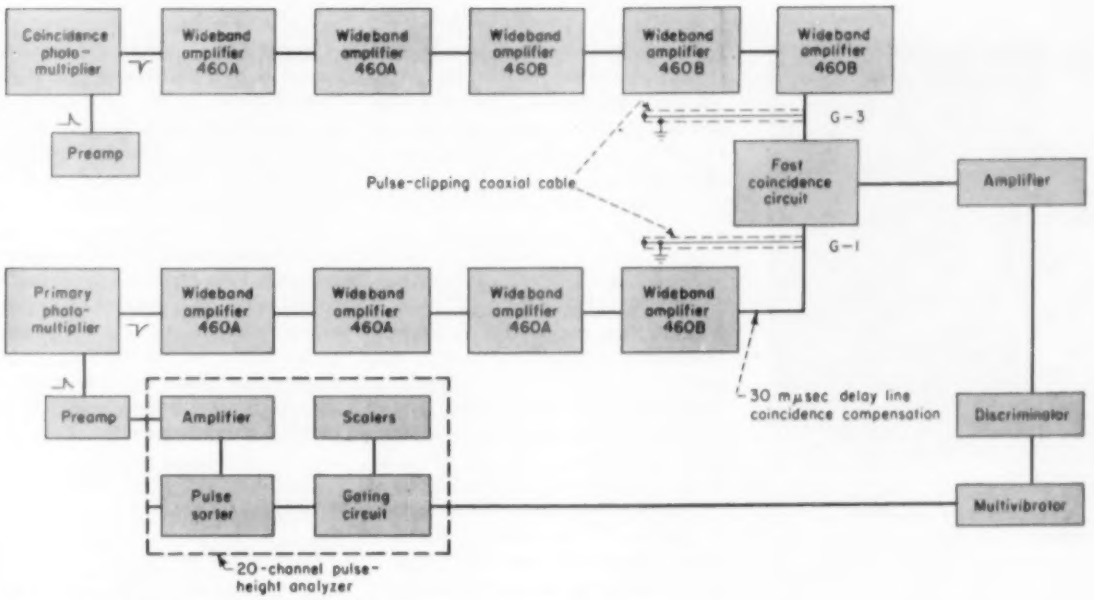

FIG. 2. Block diagram of electronics for Compton gamma-ray spectrometer

Appropriate electronics insures that only those coincidence-crystal counts that are accompanied by primary-crystal counts are recorded by the pulse-height analyzer.

Energy Range

The upper limit of gamma-ray energy that can be handled by a Compton spectrometer and still give a unique response is reached when the incident gamma rays are energetic enough to cause pair production. In the pair-production region, annihilation quanta trigger the coincident crystal and give a false measure of the incident quantum energy by the amount required to create the pair. In practice, one can operate somewhat above the 1.02-Mev threshold for pair production.

The lower limit of the usable energy range is set by the absorption of the Compton-scattered gamma rays in the primary crystal before they can escape and reach the coincident crystal. The practical lower limit of the energy range is ~200 kev. Special techniques will allow coincident counting at energies as low as 130 kev; however, such techniques severely limit the upper energy range.

In the energy range and geometry considered, 78–99% of the scattered gamma rays reaching the coincident crystal will be absorbed since the maximum possible energy of the scattered gamma ray is low, a little more than 250 kev. (The mean free path of 250-kev quanta in NaI(Tl) is about 0.8 cm.)

Design of Detector Head

The crystals are in the detector set (Fig. 1) so that incident gamma-rays Compton-scattered through an angle of 150 ± 25 deg can be detected by the rear crystal. The back crystal is as close as practicable to the primary crystal since the scattering probability per unit solid angle is low.

Forward shielding is provided by a lead casting on a steel base plate bent to form an angle of 135 deg. There is 8 in. of lead in front of either of the crystals. A minimum of 2½ in. of back shielding reduces scattered radiation. This is provided by four lead blocks shaped to enclose the photomultiplier tubes but allow passage of the incident and scattered beams.

Either photomultiplier assembly can be slipped out of the shielding by removing two screws. A removable lead plug permits visual alignment of the collimation system. The 1-in.-diameter 8-in.-long lead collimator insert is held in place by a simple key arrangement.

Electronics

A block diagram of the electronic circuitry is shown in Fig. 2. Pulses from the photomultipliers are amplified by a series of 200-Mc wide-band amplifiers of 200-ohm impedance. These amplified pulses are fed into a 6BN6 fast coincidence circuit (*6*), which produces a voltage pulse output if pulses occur in the primary and coincidence photomultipliers within 0.02 μsec of each other. After amplification, discrimination against low-amplitude noise and proper shaping, voltage pulses at the output of the 6BN6 coincidence circuit are fed into the gating circuit of the twenty-channel analyzer.

Simultaneously, the total amplified output of the primary photomultiplier is fed into the linear amplifier of the analyzer. Thus pulses are registered on the scaler bank of the twenty-channel analyzer only when a Compton gamma ray is scattered from the primary into the coincidence crystal.

Each grid of the fast coincidence circuit must respond to pulses with a rise time (10–90% of maximum) of ~0.05 μsec and a pulse length (measured at 50% of maximum amplitude) of about 0.08 μsec. Pulses to the coincidence circuit are as short as possible in duration to minimize accidental coincidences.

The spectral pulses fed directly into the linear amplifier of the twenty-channel analyzer have a rise time of about 0.7 μsec and a pulse length of about 1.4 μsec.

Figure 3a shows the complete spectrum of Zn^{65} while Fig. 3b shows the spectrum when the analyzer is gated by

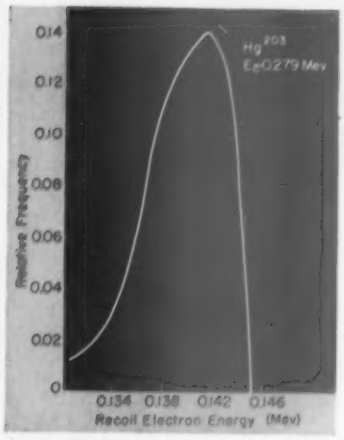

FIG. 5. Spread in recoil-electron energies resulting from spread in scattering angles

the coincidence circuit output. Only pulses corresponding to Compton events are registered then.

Figure 4 shows oscilloscope traces of the coincidence-pulse spectrum for Zn^{65} (1.112 Mev), and Cs^{137} (0.662 Mev), showing the nearly identical output pulse height for different energy gamma rays. The amplifier is followed by a Schmidt discriminator that cuts out feed-through signals appearing at the plate of the 6BN6 and provides a constant-amplitude signal to the input of the univibrator that provides a gating pulse for the pulse-height analyzer.

Energy Calibration

Energy calibration of the Compton spectrometer involves assignment of a gamma-ray energy in Mev to the arbitrary pulse-height scale of the multichannel analyzer used with the spectrometer.

The relationship between the incident quantum energy, E_γ, and the Compton recoil electron energy, E_e, where the incident quantum is scattered through an angle, θ, is given by the energy and angle function for the Compton process

$$\frac{1}{E_\gamma - E_e} - \frac{1}{E_\gamma} = \frac{1 - \cos\theta}{m_0 c^2} \equiv G$$

Solving for E_e

$$E_e = E_\gamma \frac{(E_\gamma G)}{(1 + E_\gamma G)} \qquad (1)$$

A linear relationship exists between the electron energy absorbed by a NaI(Tl) crystal and the height of the resultant photomultiplier pulse (5). From this it can be seen that a unique, though nonlinear, relationship exists between the incident quantum energy and the height of the photomultiplier output pulse resulting from the recoil electron.

From Eq. 1, for

$$E_\gamma G \gg 1 \qquad E_e \simeq E_\gamma$$
$$E_\gamma G = 1 \qquad E_e = \tfrac{1}{2} E_\gamma$$
$$E_\gamma G \ll 1 \qquad E_e \simeq E_\gamma{}^2 G$$

Scattering angle. For point scatterers and point detectors the scattering angle, θ, is precisely determined. In practice it is necessary to use crystals of finite extent. Hence one must determine the average scattering angle between the direction of the incident and scattered gamma rays. This was done by dividing front and rear crystals into equal volume elements and taking a representative sampling of the available scattering angles between front and rear crystal elements. The average angle as determined by numerical integration is 150 deg.

Figure 5 is a typical estimate of the spread in recoil-electron energies arising from distribution of scattering angles as weighted by the differential Compton cross section. The principal effect of this energy spread is to increase the peak width slightly ($\sim$5%).

Spectra for a number of monoenergetic gamma emitters* were obtained using the front crystal of the Compton spectrometer as a conventional single-crystal spectrometer (7). The mean pulse height of the total-absorption peaks from these spectra, P_{tot}, are linearly related to the energies of the incident gamma rays; thus

$$E_{tot} = (0.00145\, P_{tot} + 0.026)\ \text{Mev}$$

Figure 6 shows the Compton spectra obtained from Zn^{65} and Cs^{137}. In addition to a Gaussian-shaped peak there is a tail that extends to the low-

* Ce^{144} (0.134 Mev), Hg^{203} (0.279), Na^{22} (0.511), Cs^{137} (0.662), Zn^{65} (1.112), Na^{22} (1.278).

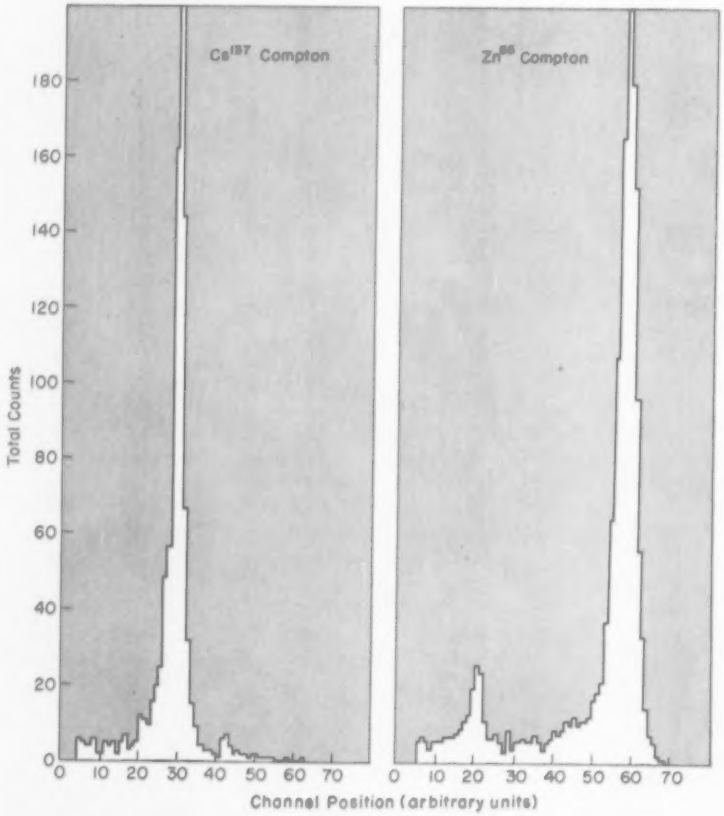

FIG. 6. Compton spectrometer calibration spectrum for Cs^{137} and Zn^{65}

energy cut-off point and amounts to about 17% of the total Compton-spectrum counts.

Whyte (*4, 8*), Maienschein (*3*), and the authors have attempted to explain these tail counts. It is believed that they are true coincidence counts, not background; they do not arise from gamma-ray degradation in the source, scattering from the lead shielding or collimator, or energy lost in the front crystal by escaping electrons or bremsstrahlung.

We agree with Whyte and Maienschein that the tail counts arise from some type of interaction of the incident gamma rays in the front and back crystal other than single Compton scattering, perhaps multiple scattering. We have observed that the ratio of tail counts to total counts decreases with incident beam diameter.

Equation 1 was used to predict the recoil energy, E_e, using 150 deg as the average scattering angle. Mean Compton-peak pulse heights, P_e, were plotted against this recoil electron energy. The resulting points were linearly disposed but too low in pulse height compared to the total-absorption-peak calibration line, Fig 4. To fit the total-absorption peak calibration, it was necessary to assume a uniform energy loss from the crystal of about 15 kev. With this assumption the Compton recoil electron energy calibration is

$$E_e = (0.00145\,P_e - 0.041)\ \text{Mev} \quad (2)$$

Combining Eqs. 1 and 2 and using a value of 150 deg for θ, the energy calibration for this particular spectrometer can be obtained.

Efficiency

The counting rate of the Compton spectrometer depends upon the number of scattered photons from the front crystal that reach and interact with the back crystal (Fig. 1). The probability of a rear-crystal interaction was calculated from the geometry of the two crystals taking only primary processes into account.

Factors considered were:

1. Attenuation of the incident beam in the front crystal, $e^{-\mu x}$.

2. Differential cross section for scattering at the scattering angle into the solid angle subtended at the scattering point by the rear crystal.

3. Attenuation of the scattered beam in the front crystal.

4. Probability of interaction in the rear crystal.

An expression combining these factors was integrated over the front crystal volume to obtain the efficiency function. Since the algebraic formulation of the various path lengths in the crystals did not lead to readily integrable expressions, an approximate simplified geometrical model was used.

Following Whyte (*8*) "true" absorption coefficients were used for the incident and scattered quanta to approximate the effect of multiple scattering. Figure 7 shows the theoretical curve and the experimental points. An average scattering angle of 150 deg was used in calculating these efficiencies.

Measured efficiency. The experimental calibration of Compton-spectrometer efficiency involved the determination of relative source strengths and efficiency measurements with the sources.

Source strengths were determined by obtaining the pulse spectrum using a separate single-crystal scintillation spectrometer. The distances used were such as to give a total counting rate in the front crystal of ~500,000 cpm, which was high enough to give reasonable Compton counting rates (1,000 cpm) but not high enough to give dead-time losses. Total counting rates were calculated from the total-absorption-peak counting rates by using Maeder's (*9*) "poor-geometry" peak-to-total curves. (A preliminary check had established their validity at the distances used in this calibration.)

These total-spectrum counting rates were converted to total incident quanta by means of the calculated crystal efficiency. Absorption coefficients for NaI used in these calculations were taken from G. R. White's (*10*) theoretical values. Heath and Schroeder (*11*) discuss the details and some of the difficulties in calibrating absolute source strengths with scintillation counters.

The efficiency measurements proper consisted of taking pulse-height spectra with the Compton spectrometer for each source at the same distance at which it was calibrated. Then the counting rate for counts under the Gaussian was divided by the calibrated counting rate for that source corrected for radio-active decay and for differing effective solid angles introduced by the collimator. These experimental efficiencies are plotted in Fig. 7 along with the theoretical curve discussed before.

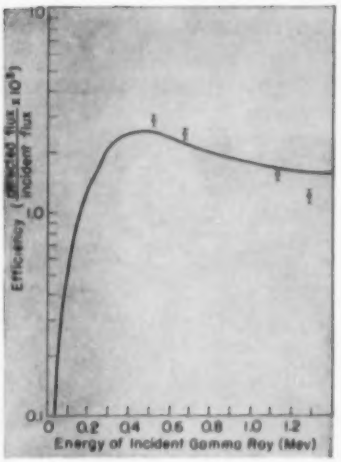

FIG. 7. Efficiency of Compton spectrometer based on Compton peaks only and using the "true" absorption coefficients of G. R. White (10). Experimental points are also shown

Resolution

One method of measuring the dispersion of pulse heights about their mean is to divide the full width of half-maximum of the pulse-height distribution curve, by the mean pulse height. This quotient is known as the resolution, R, and is usually said to be proportional to $E^{-\frac{1}{2}}$, where E is the energy released in the crystal by electrons.

When the experimentally measured resolutions of the Compton peaks were plotted against Compton recoil electron energy on log-log paper, the slope of the straight line fitting the points was found to be 0.611 rather than 0.500, viz

$$R = 0.0773\ E_e^{-0.611}$$

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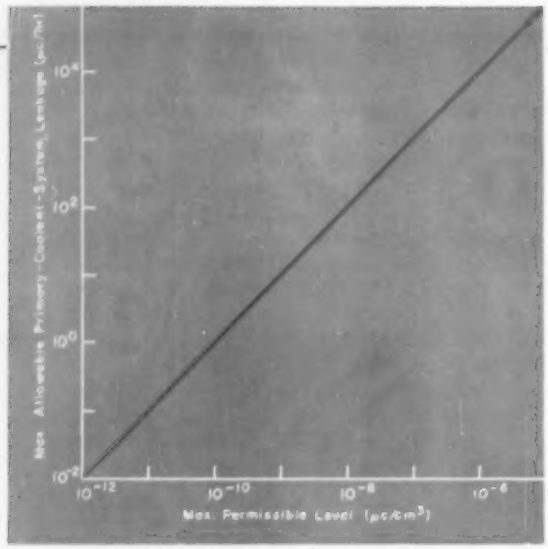

FIG. 1. Leaktightness requirements of primary coolant system for 10^7-ft³ building with 5,000-ft³/min ventilation

Testing

Nuclear-Plant Leaktightness

By J. P. VERKAMP and S. L. WILLIAMS
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LEAKTIGHTNESS PROGRAM SHOULD INCLUDE:

- **Determination of how extensive a program can be justified**
- **Design of components and connections for cleaning and inspecting facility, minimum-size welds, and convenient-size subassemblies**
- **Enforceable cleanliness and inspection program**
- **Leaktightness requirements in all component specifications and all subassembly work; sequence operations to permit several rechecks of leak-susceptible components**
- **Extra care to insure sound welds in component and subassembly work and final system assembly**
- **Integration and sequencing of over-all fabrication, inspection, testing, and assembly work**

ALTHOUGH LEAKAGE CONTROL has been an important consideration in engineering and constructing remote nuclear power plants, greater emphasis on leaktightness will be necessary for plants located in populated areas. Since the use of sewers, streams, or the atmosphere for dissipating leakage and medical surveillance of the local population are impractical, a leaktightness program must be instituted covering design, fabrication, and final assembly of the plant.

* Operated for the U. S. Atomic Energy Commission by the General Electric Co.

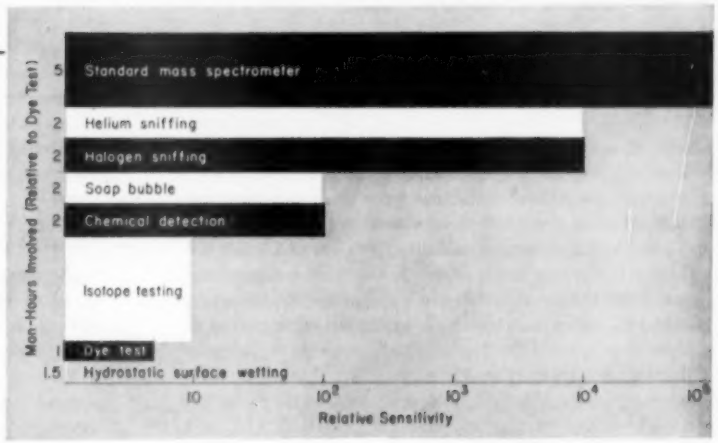
Design

In designing piping for nuclear plants, particular attention should be paid to selecting components that will minimize leaks. For example, socket weld fittings have been used on small piping as a general construction practice to facilitate field assembly. But welding these fittings to obtain leaktight joints is frequently difficult, and the fittings do not lend themselves to radiographic testing after installation.

Early pressurized-water systems required a number of auxiliary systems composed of numerous small pipe connections. Here, careful selection of

(Text cont. on p. 56)

These Methods Are Used For Tests



Here's How They Compare

MASS SPECTROMETER—HOOD TEST. Tests entire surface; sums total leakage; can be used to localize leaks.

Procedure: Draw 50-micron vacuum in test volume; introduce helium into rubber or plastic bag over test surface. Draw sample of evacuated gas into mass spectrometer. Ultimate sensitivity reached by evacuating all gas through tester. Leak pin-pointed by using fine helium jet as blanket.

Comments: Sensitivity depends on proportion of gas passing through tester; properly applied, method develops full inherent sensitivity of tester. When attempting full sensitivity on large volume, response is slow and outgassing is time consuming; cleanliness requirements stringent to avoid outgassing problems.

MASS SPECTROMETER—SNIFFER TEST. Useful step in approaching high degree of leaktightness.

Procedure: Pressurize test volume with helium and air so that pressure differential drives helium through leaks; helium concentration is 20% or greater. Probe outer surface with nozzle in short hose leading to tester; mark leaks. When leaks are repaired, repeat test.

Comments: Efficiency depends on operator's experience and diligence; careful probing is tedious. Cleanliness is essential to avoid masking leaks.

MASS SPECTROMETER—BOOT TEST. Localizes individual leak; permits rapid repetitive testing of parts for which specialized boots can be developed.

Procedure: Introduce helium into test volume; apply cup or boot to portion of outside surface; evacuate gas between boot and surface of tester.

Comments: Sensitivity comparable to previous method. Response unaffected by size or configuration of test volume; almost as rapid as sniffer test. Outgassing time short. Cleanliness only sufficient to avoid masking leaks being sought since large-volume outgassing problems are avoided. Probably does not develop full tester sensitivity; sealing boot to test surface is major problem. Single boot not applicable to every test.

HALOGEN SNIFFING. High-sensitivity test.

Procedure: Pressurize system to 100 psig with halogen-air mixture; generally use halogenated hydrocarbons, e.g., Freon-12 at 20% conc. Cover test surface with probe at ½ in./sec. Fan draws continuous air samples into detector containing halogen-vapor-sensitive element. Portable control unit contains power supply, amplifier, indicator, and loud-speaker.

Comments: Less expensive than mass-spectrometry testing, but less satisfactory; may leave traces of halogen in system; sensitivity to airborn contaminants gives false leak indications under field conditions.

SOLUBLE-DYE TEST. Visual observation of leak.

Procedure: Fill system with water containing fluorescent dye, e.g., Calco uranine B-4315 (American Cyanamid); much smaller fluorescent-dye concentration with u-v light pin points leak than possible with ordinary dye. Raise system to 1.5 × design pressure and hold for 6–8 hr. Depressurize and inspect under u-v.

SURFACE-WETTING TEST. Hydrostatic water test; generally used for component and subassembly tests where volumes are relatively low.

Procedure: Fill system with water to 1.5 × design pressure. Isolate system. Drop in pressure indicates leak rate. Detect leaks by noting weeping at surface.

CHEMICAL DETECTION.

Procedure: Introduce tracer compound inside test volume, explore outside with "detector." Suitable test is white fumes given off by acid-base reaction between ammonia and carbon dioxide or hydrogen chloride; or halogen torch, whereby halogenated hydrocarbon as tracer imparts green color to torch flame.

Comments: Several chemical methods have about same sensitivity.

SOAP-BUBBLE TEST. Finds larger leaks in assembled system before employing more sensitive methods.

Procedure: Pressurize test volume with air. Paint leakage areas with soap solution. After repairing leaks, repeat.

Comments: Relatively high sensitivity with proportionally low expenditure of man-hours.

RADIOISOTOPES. Used after repairing major leaks.

Procedure: Fill system with radioisotope solution (Rb^{86} often used); initial concentration generally about 0.01 μc/ml of water. Using weld numbers as guide, wrap all pipe welds, valve bonnets, vent plugs, etc. with absorbent ¾-in.-wide absorbent tape. Raise filled system to 1.5 × design pressure and hold for 6–8 hr; then generally cycle several times, depressurize system, remove tapes, and count. With tapes giving 150 cpm or more with standard-geometry G-M tube, welds are inspected and repaired.

Comments: This is variation of standard water hydrostatic testing procedure to achieve greater sensitivity.

A Case Study—Leaktesting a Sodium-Cooled Plant

A KAPL-operated sodium plant (*5*) with a primary-coolant volume of several hundred cubic feet has shown unusually high freedom from leaks. To provide the plant with a primary coolant system as leaktight as possible, an all-metal, all-welded system is used.

Previous experience with sodium showed that where high system-tightness standards were set, the occurrence of leaks during operation was reduced to near the vanishing point. Since some seemingly insignificant leaks are actually relatively large perforations that are partially masked by occlusions and will enlarge under operating conditions, any detectable leak was assumed to represent a flaw that should be repaired. Therefore, with components, and where possible with entire systems, mass-spectrometer-quality tightness was required.

Leak Specifications

Since the assembled system might not be accessible for high-quality mass-spectrometer testing, an over-all component, subassembly, and field weld-testing program was substituted. The program assured that no individual leak would exceed the lower limit detectable by the mass spectrometer leaktester under field conditions. This assured that the system would remain leaktight during operation and placed an approximate ceiling on over-all system leakage.

The program specified that: (a) all small components tested to 0.005 mcfh (ft^3/hr at 1-micron Hg) and large components to values consistent with their volumes; (b) all small subassemblies tested to 0.005 mcfh and large subassemblies to values consistent with their volumes before inclusion in the system; and (c) all field welds tested to 0.005 mcfh during assembly. Since there were about 100 subassemblies and field welds, the final system would be tight to about 1 mcfh over-all leakage.

Inspection Procedure

Rigorous handling, inspection, and testing procedures of all components and subassemblies were instituted:

1. Component manufacturers supplied an outline of their cleaning procedures, leaktesting schedules, and packaging procedures. Leaktesting was conducted at several steps during manufacture since a leak in an inaccessible part of a component is difficult to discover and repair after assembly. Cleanliness, essential in the low-leak-rate ranges, must be maintained for repeat and subassembly tests; thus, packaging for shipment is important.
2. Inspection on receipt of components included recleaning as necessary and retesting for leaks.
3. The subassemblies were inspected and leak checked just prior to inclusion in the system since many of the subassemblies and components were fabricated in the vendor's shops and because fit-up work at the construction site involved some handling and cutting of subassemblies.
4. Finally, the field welds were checked by the mass-spectrometer boot technique.

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piping components was necessary to obtain a leakproof system. Butt welds or other closures satisfactory for welding fabrication will greatly reduce leaktesting and repair work after assembly.

Leaktesting

The degree of tightness required for a nuclear system can be appreciated from the table and Fig. 1. As an example, the maximum leak rate for fission gases that have a maximum permissible level of 2×10^{-6} $\mu c/cm^3$ (based on Xe^{135}) would be 2×10^4 μc/hr in a 10^7-ft^3 building (*1*). Although the activity of fission gases varies with reactor power and previous operating history, an allowable leakage rate of 10^{-6} cm^3/sec is conceivable. Such low leak rates require specialized techniques for rapid measurement.

Excessive leakage can produce a direct radiation hazard during maintenance. Figure 2 shows the dose rate that might be expected from leaks in a sodium-cooled plant.

Applications of the various leaktesting methods vary with the type of heat-transfer fluid and the materials of construction used. The leak-detection methods that have been used for pressurized-water and liquid-metal systems are summarized on p. 55.

Sensitivity

The graph (p. 55) does not indicate ultimate sensitivity that can be attained by modification and the expenditure of greater amounts of time. For example, the dye or chemical-detection tests could be improved by using absorbent strips, as in the radioisotope test, but man-hours would be increased.

Mass spectrometry is capable of the greatest sensitivity (*4*). The unit especially designed for helium leaktesting attains a sensitivity of 1 part helium in 200,000 parts air, thus being capable of detecting a leak of about 2×10^{-4} mcfh (micron ft^3/hr—a leak rate of 1 mcfh is such that when applied to 1 ft^3 under high vacuum, the pressure rises

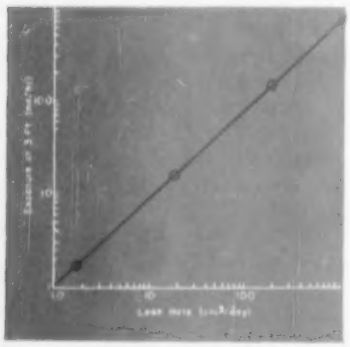

FIG. 2. Radiation exposure 3 ft from point-source leak vs. leak rate

Max. Permissible Levels in Air*

Radioisotope	*MPL* ($\mu c/cm^3$)
H^3	2×10^{-6}
Na^{24}	2×10^{-6}
K^{42}	2×10^{-6}
Cr^{51}	8×10^{-6}
Mn^{56}	4×10^{-6}
Xe^{135}	2×10^{-6}
Po^{210}	7×10^{-11}
U (natural)	1.7×10^{-11}
Pu^{239}	2×10^{-12}
Beta-gamma emitter (isotope unknown)	1×10^{-9}
Alpha emitter (isotope unknown)	5×10^{-12}

* Reproduced from Radiological Handbook, U. S. Dept. Health, Education and Welfare (1954).

The final leaktest of subassemblies uncovered only two detectable leaks, one in a 2-in.-pipe elbow, the other in a section of 2-in. pipe. A preliminary vacuum test of the completed system indicated it met desired tightness. No leaks occurred during the first six months operation.

Other factors contributing to system tightness were design and welding. The primary coolant system is designed to contain relatively few small pipes or fittings. The system was amenable to subdivision into a relatively small number of subassemblies and components. For strength as well as leaktightness, all welds were subjected to a dye-penetrant test of first and last pass, followed by radiographic examination. A mass-spectrometer test also indicates soundness of a weld.

In addition to fabricating techniques, choice of materials is important to minimize leaks because of the possibility of flaws. For example, in using nickel-bearing stainless steels, the unstabilized types give "cleaner" welds; the stabilizers, such as Cb and Ti, tend to cause carbide inclusions in the welds. Where a stabilized type is required, tight specifications on carbon and stabilizer content may be desirable. Commercial specifications on type-347 stainless call for stabilizer not less than ten times the carbon content and not more than 1.0%. Where needed, 347 stainless has been procured with 0.06% carbon, max., and columbium eight times carbon.

To minimize fissures and cracks in welds, the composition of the weld should be such that it contains about 4% ferrite. By specifying the proper filler-rod composition, the weld composition can be made nearly as desired. For example, in welding tube-mill products of 347 stainless, which commonly runs well on the austenitic side (no ferrite), a filler rod of 8–10% ferrite produced welds containing the desired 3–4% ferrite.

However, the type of weld, preparation, and weld dimensions, as well as material composition, must be considered in estimating the final weld composition. Trial welds are the best method of obtaining the necessary ferrite composition data. Another indirect means of controlling welds through material specifications is obtained by specifying weld electrode coatings. For example, where ease and rapidity of welding is important, a titania-bearing coat is used on electrodes. The titania increases the fluidity of the flux; however, the rapid welding and reduced puddling resulting from the use of such a coating sometimes is considered to contribute to slag inclusions in welds. If weld quality is paramount, a straight lime-coated rod should be considered.

Since the skill of the welder is most important in producing good welds, attention should be given to details in welder qualification tests. Tests should be used that are representative of the work to be done. The use of dye-penetrant tests to assure soundness of first and last pass of a weld is good practice and reduces the amount of repair time. Radiographic inspection of the completed weld is highly desirable. In thick material requiring many weld passes, more frequent testing should be done.

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1 micron of mercury per hour due to atmospheric in-leakage). To obtain this ultimate sensitivty, the surface to be tested must be scrupulously clean and extreme care must be exercised in the test procedure. These requirements may be met under special conditions, but for most practical field work, 0.005 mcfh is considered the limit.

Testing Procedure

A progressive type of leak-detection procedure making use of several tests gives the best results.

Hydrostatic procedure with water generally is used for testing components and subassemblies. The soap-bubble test is attractive for finding the large leaks in the assembled system before employing more sensitive methods—large leaks mask the smaller ones. In one large pressurized-water nuclear system, ~63% of the pre-operational leaks were discovered by this method in 15 days. After repairing the leaks found by the bubble test, a hydrostatic water test should be performed on high-pressure systems; exposure of the system to 1.5 times the design pressure may open additional leaks.

The system is now ready for a high-sensitivity leak test, e.g., halogen or helium sniffing or standard mass-spectrometer testing. The choice largely depends on the degree of tightness required.

The most satisfactory procedure has been to localize leaks by standard mass-spectrometer testing of various portions of the system under vacuum. Then the suspect areas can be worked over using the spectrometer as a helium sniffer. If a higher degree of tightness is required, the boot technique should be employed.

Omitting the standard mass-spectrometer testing for leak localization appears to result in prolongation of the helium-sniffing test. Providing the operator with a known leak to search out markedly increases his diligence.

Although this type of rigorous leaktightness program increases the cost of individual components and subassemblies, it offsets a comparable expense in rework time after the system is completed. The specific advantages gained in a program of this type, rather than relying on corrective measures after assembly, are:

1. The responsibility for achieving a particular degree of leaktightness is properly divided between designer, manufacturer, fabricator, and constructor.

2. Unpredictable delays in placing the system in operation after assembly are avoided.

3. A specific leaktightness goal can be systematically approached.

Rather rigid test requirements were of necessity placed on the first nuclear power-plant prototypes. However, as methods and materials improve and experience is gained, considerable simplification of the leaktightness procedures should result.

* * *

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Testing Operating Safety of a Water-Boiler Research Reactor

Experiments to determine operating characteristics of a new reactor are made before beginning routine operation. These tests provide data on which to base safe standard operating procedures

By J. W. FLORA* and J. W. SHORTALL†
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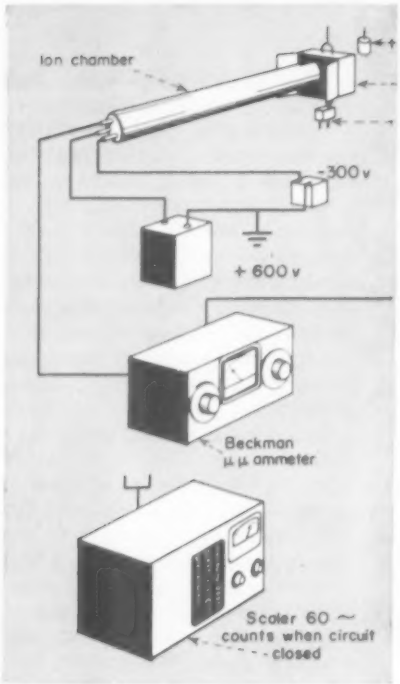

FIG. 1. Arrangement for testing safety system. System uses γ-compensated ion chamber (RCL Mark-17, Model-2), whose signal is sent through 90 ft of RG-62U

OPERATIONAL SAFETY performance of the Livermore Research Laboratory (LRL) water-boiler-type research reactor was thoroughly investigated before the reactor was put into routine use for experiments. Factors tested include: temperature coefficient of reactivity, transient behavior, buildup and decay of volatile activity, danger coefficients, effect of loss of coolant, poisoning effect of an absorber placed in the core, control-rod calibration, response time of safety devices, and effects of voids in the reflector. These tests led to safe routine procedures.

* PRESENT ADDRESS: Atomics International Div., North American Aviation, Inc., Canoga Park, Cal.
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Temperature Effect

The temperature coefficient of reactivity was measured as $-0.026\%\ \Delta k/k/°$ C between 10.3 and 37.7° C. The measurements were made by allowing the reactor to rise on its "free" period (both control rods fully withdrawn) after core temperature had been adjusted to the desired value. Three period measurements were taken, over different power ranges, on each rise so as to check the stability of the period. Reactivities were calculated using the inhour formula (*1*).

Figure 2 shows the data and also

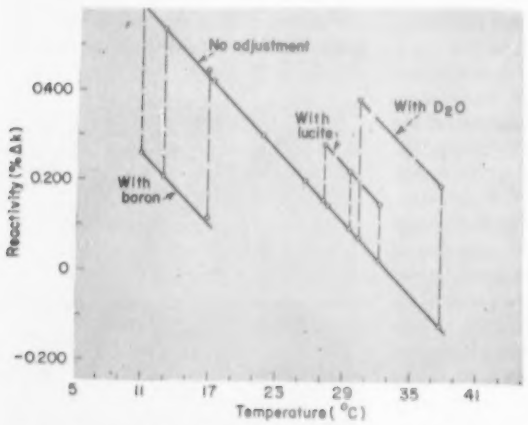


FIG. 2. How core temperature affects reactivity. To keep period conveniently measurable, boron was placed in core cavity for low-temperature tests and Lucite and D_2O were inserted for high-temperature tests

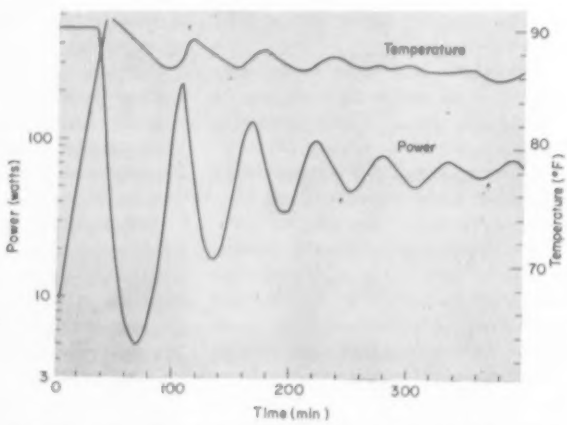
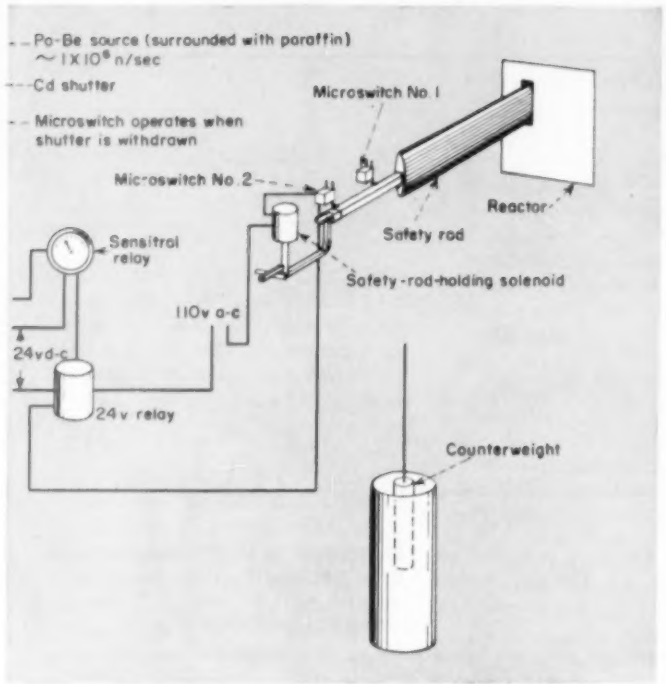


FIG. 3. Oscillation of power and temperature due to temperature coefficient of reactivity. After about 1 hr at 500 watts with no coolant flow, temperature rose so high that power dropped; oscillations resulted. Control rods were kept withdrawn



coaxial cable (13$\mu\mu$f/ft) to Beckman (Model V-5571) where it is amplified and sent to Weston Sensitrol (Model-705). At closing of this relay, second one opens to interrupt circuit of holding solenoid for safety rods, which travel total of 3 ft via acceleration by lead counterweights

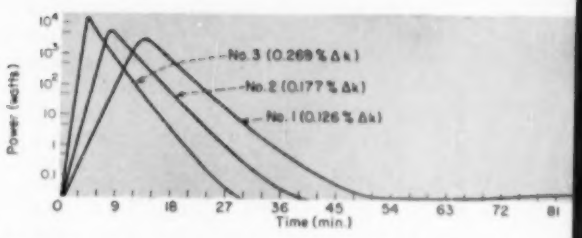


FIG. 4. How power varies in transients involving various reactivities

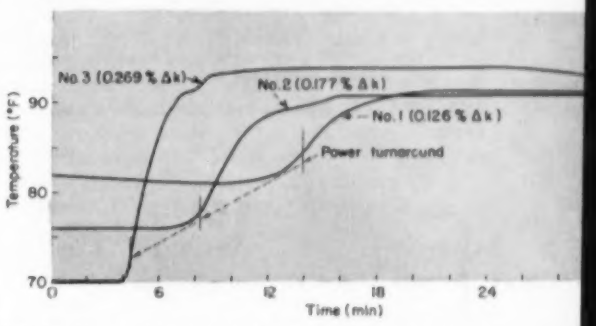


FIG. 5. How temperature varies in transients involving various reactivities

shows that the curve slope is not changed by putting absorber or moderator materials in the central exposure facility.

Transient Behavior

A power-temperature oscillation experiment was performed to demonstrate the effect of the temperature coefficient. Reactor power was allowed to rise to 500 watts while no cooling water was circulated through the core. The 500-watt level was maintained for about 1 hr by the automatic control system, until the reactor was no longer capable of remaining critical with all control rods removed because of fuel-temperature rise from power dissipation in the core. At this time, with all rods removed, the reactor power was allowed to begin oscillating as the core was alternately cooled by conduction and heated by power dissipation.

Figure 3 shows the power and core temperature (indicated by iron-constantan thermocouples welded to the outside of the core sphere).

A second experiment involved the release of the reactor from a "zero"-power condition with reactivities of three values. Knowledge of the temperature coefficient and heat capacity (Table 1) allowed simplified calculation of peak powers that should be expected. For example, consider that the reactor is released from "zero" power with a reactivity of 0.1%. It will require 6.96×10^4 watt-sec to compensate for the first increment considered in the step calculation—0.026% $\Delta k/k$, which corresponds to 1° C. From the equation

$$E = \int_0^T P_0 e^{t/\tau}\, dt$$

where E is the energy dissipated in time t if the reactor begins its rise from the power level P_0 on a period τ. Substituting the proper value for E and τ and choosing P_0 as 0.1 watt for convenience, it is found that after 713 sec the reactor has raised its temperature 1° C. The power level after 713 sec is given by $P_1 = P_0 e^{t/\tau}$, or 886 watts. By repetition of the process through four cycles we find that the peak power is 1.96 kw. This result will be somewhat high since it is given by a broken-line function.

TABLE 1—Heat Capacity of Core

Item	*Weight (kg)*	*Heat capacity (10^3 cal/°C)*
Solution (assume equiv. weight of water)	15.60	15.60
Stainless steel:		
Sphere	4.95	0.97
Cooling coil	0.63	
Glory-hole tube	0.38	
Top pipe (6 in.)	0.72	

Data from the three transients is given in Table 2. The third transient involved very nearly the same reactivity that is "built into" the reactor. This case indicates total exposure to personnel in the immediate vicinity of the reactor shield would not be appreciably higher in an uncontrolled transient than during 1 hr of normal operation. This demonstrates the "inherent safety" of low-power water boilers.

Figures 4 and 5 show how power level and shell temperature varied. The transients are on a common time scale. Figure 6 shows a linear relationship between energy release and reciprocal period for this class of excursion.

The sharp turnaround observed in the third transient (Fig. 4) is possibly due to either: (a) unequal heat and/or bubble distribution in the core, resulting in a more subcritical region, comparatively speaking, in the center of the core, or (b) the short-time accumulation of a large amount of gas

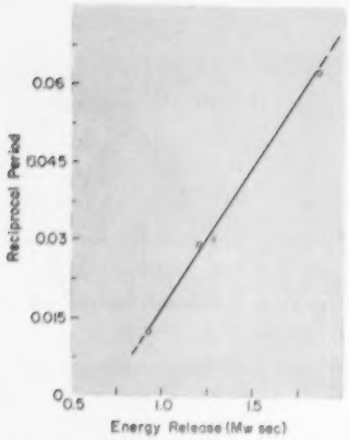


FIG. 6. Energy release vs. reciprocal period

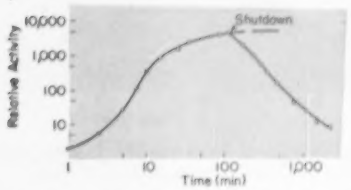


FIG. 7. Volatile activity buildup and decay

within the fuel solution. Inflections reached just prior to the plateaus in Fig. 5 are probably due to density changes in the fuel solution from bubble formation and consequent poorer heat transfer.

Volatile Activity

The gross gamma activities in the sweep-gas lines as functions of time from startup and shutdown were measured. The gas system plumbing arrangement makes it possible to pass a side stream of the circulating gas through a line outside the biological shield. A length of ¼-in.-i.d.-by-1/16-in.-wall Tygon tubing was installed as this external line, the gas pump turned on, and a commercial gamma-ray detector positioned near the line. The output of the detector was fed to a d-c amplifier, which in turn drove a strip-chart recorder. The system was calibrated with a Co^{60} source before the experiment was performed. The detector has an energy response that is essentially flat from 80 kev.

The buildup of activity in this line and also the decay of the gross products measured after the reactor was shut down and the gas pump turned off are shown in Fig. 7. The majority of volatile activity is present within 45 min after startup.

The fission-product gases are highly toxic and are an extremely mobile source of hazard. Their containment must be assured in case of accidental rupture of the reactor system. To illustrate the degree of hazard involved, assume that the LRL reactor were operating at nominal power and a system rupture occurred, and the gaseous products uniformly dispersed throughout the building (50 × 50 × 20-ft). The atmosphere would be 10^5 times prescribed breathing tolerance (*2, 3*). Without an iodine trap the situation would be even less favorable. To gain the proper perspective of this hazard it must be realized that the background source for such a reactor (Po-Be, 10^6 n/sec) offers a potential air contamination (in this building) of more than 10^8 times breathing tolerance.

TABLE 2—Power Transient Data

Characteristic	*Transient*		
	No. 1	*No. 2*	*No. 3*
Reactivity, %	0.126	0.177	0.269
Stable period, sec	57	34	16
Peak power, kw			
Measured	3.1	5.8	15.8
Predicted	3.2	7.8	20.8
Total energy, watt-hr	261	335	517
Energy to turnaround, watt-hr	109	108	128
Energy to departure from initial period, watt-hr	6.8	13.6	27.7
Temperature rise of core, °C			
Measured, total	5.3	8.1	13.0
Calculated, to turnaround	4.9	6.8	10.5

Danger Coefficients

Danger coefficients were taken on a variety of cylindrical samples placed in the glory hole of the reactor—a 1.1-in.-i.d. tube passing through the center of the core. The results serve as reliable guides for estimating the reactivity effects of proposed samples and containers.

Reactivity values assigned to the materials were determined by period measurements. In each case periods were taken periodically with no sample in the glory hole to determine the corrections necessitated by fuel-temperature change. To minimize these corrections, no cooling water or sweep gas was circulated through the sphere. A set of three periods at different power levels was taken in each measurement

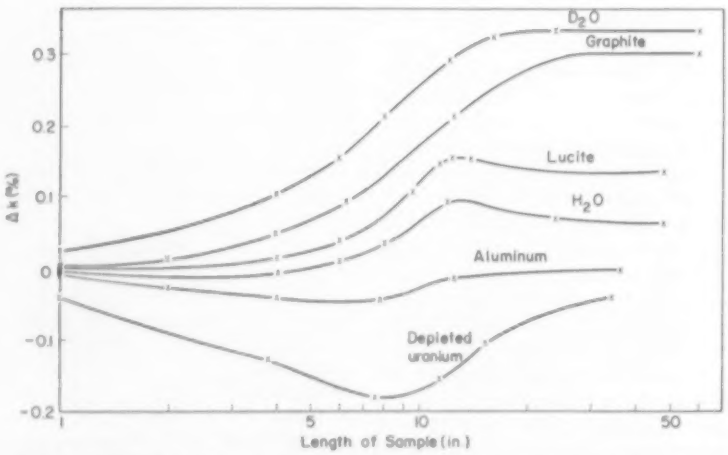


FIG. 8. Effect of centering materials of various lengths in central irradiation facility

to check the stability of the period. The control-rod displacement technique would have been used had interaction between rod and very long samples not been known to occur.

Samples. The samples of graphite, aluminum, and Lucite used were of 1-in. diameter. For liquid samples, the containers were thin-walled 3S-aluminum tubes of 0.94-in.-i.d., and were completely filled. Danger-coefficient data in Fig. 8 have been corrected for the effect of the containers. The D_2O used was analyzed by the nuclear-magnetic-resonance technique and found to contain 2.2% H_2O. The graphite used was of pile grade—natural diffusion length = 52 cm. The uranium used was depleted in U^{235} to ~60% of its natural content. It was used in the form of solid metal cylinders of 0.92-in. diameter. All samples were geometrically centered in the glory hole.

Coolant Loss

By period measurements it was determined that removing the cooling water decreases reactivity by 0.28%. Surprisingly enough, the reactivity contribution of the cooling water is very nearly that of an equal volume (125 cm^3) of fuel solution. In higher-power water boilers of this type the effect probably would be even more pronounced since they normally operate with fuel that is more hydrogen lean. This fact coupled with the greater coolant flow rates and volumes to be used in boilers operating above 25 kw offers the possibility of another safety device for such reactors. A compressed air cylinder located near the sphere and attached to the cooling line through a solenoid valve could displace the water from the coils in relatively short time. The solenoid valve releasing air into the line would also interrupt the water supply. The air pressure required to displace water from the cooling coils would be sufficiently low so as to offer no "blow out" hazard.

Absorber Traverse

The poisoning effect of an absorber placed within the core should be proportional to the square of the flux at its location. To determine this function experimentally and thus insure accurate estimates of reactivity effects by long samples, a small sample of boron was passed through the sphere in steps and the critical settings of the fine control rod were noted.

The Livermore Research Reactor . . .

. . . was first made critical in November, 1953. It was the sixth water-boiler-type reactor to be put into operation in the U. S. Its predecessors were LOPO, HYPO, SUPO (all at Los Alamos), the Water Boiler Neutron Source (Downey, Cal.), and the North Carolina State College reactor (Raleigh, N. C.) (*4*). All but LOPO and HYPO are still in existence. Another water-boiler reactor is to go critical soon at Armour Research Foundation in Chicago.

Power. The Livermore water boiler operates at a heat-production level of 500 watts, but has instrumentation, control, gas-recombination, and cooling capacity for 2-kw operation. It is loaded with 0.3% excess reactivity at 72° F.

Core, reflector, shield. The reactor has a 12.5-in.-dia. spherical core embedded in a 5-ft right cylinder of graphite, which serves as reflector. The core contains 14.5 liters of a sulphate solution containing 694 gm U^{235}. The shield consists of 5 in. of lead, 3 ft of concrete, and a 4-ft wood roof.

Control. Four control and safety rods containing boron move tangentially along the sides and underneath the sphere. Effectiveness of the two control rods is 2% Δk; the two safety rods have 2.5% Δk. One of the control rods is driven by a servomechanism.

Cooling, gas removal. A helical cooling coil 160 in. long conducts 45° F distilled water through the core in a closed circuit. The reactor sweep-gas system operates at negative pressure on a closed cycle; it contains an $AgNO_3$ iodine trap and explosion traps in addition to the catalyst bed. Gas disposal is intermittent.

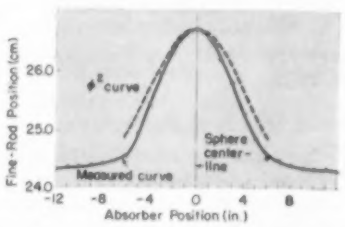


FIG. 9. How a small (20 mg) sample of boron at various locations along the core diameter affects reactivity (as expressed by fine-control-rod position)

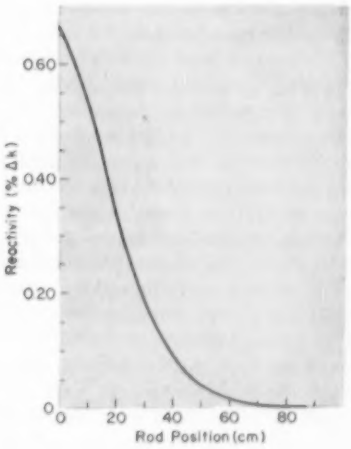


FIG. 10. Calibration of fine-control rod. Curve is typical for slab-shaped rods outside spherical core

The sample was composed of 20 mg of boron spread (non-uniformly) upon and attached to the surface of a $\frac{1}{4} \times 1 \times \frac{1}{16}$-in.-thick Lucite strip. This sample was wedged in the center and on a diameter of a 6-ft-long thin-walled aluminum tube. Figure 9 is a graphical representation of the data gathered. The function approaches that of the square of the flux but the cavity effects of the glory hole are easily distinguishable.

Boron Effectiveness

The boiler has been experimentally calibrated for sensitivity. Boron, in increasing quantities, was added to the core (via the glory hole) and the reactivity change was noted. Five samples of boron powder were made and tested. The boron was brushed uniformly on scotch tape and the net weight of boron determined. About 7 mg were contained on each 4 × 1-in. sample, giving a layer of boron somewhat less than 0.3 mg/cm^2. The results of the experiments are shown in Table 3.

Control-Rod Calibration

To expedite some types of danger-coefficient measurements a complete calibration of the fine control rod was made. The calibration was arrived at

TABLE 3—Boron Effectiveness

Total B in sphere (mg)	$-\Delta k/k$ (%)	$-\Delta k/k$ (%)/*gmB*
8.02	0.028	3.49
15.64	0.055	3.52
22.44	0.078	3.48
29.25	0.101	3.45
36.25	0.124	3.42

by successive period measurements. Extension of the measurements from the normal critical position to the "all in" position was accomplished by insertion of restricted amounts of D_2O in the glory hole and cooling the fuel solution to 60° F. As shown in Fig. 10, the maximum reactivity controlled by the rod was 0.669%.

Safety Response Time

A test was made to determine the length of time, under normal operating conditions, that is required for the safety rods to be seated after a scram-level flux is presented to one of the ion-chamber power detectors.

The reactor is so interlocked that it will shut down automatically and/or cannot be started up for any of these reasons: excessive power level, excessive power-increase rate, excessive sweep-gas pressure, excessive fuel temperature, excessive hydrogen concentration in sweep gas, earthquake, low gas-flow rate, water leak in gas-pressure regulating system, operator action, instrument power lost, startup source withdrawn from reflector, biological shield doors open, or safety switches open inside biological shield.

The excessive power-level is the only automatic safety circuit that can be evaluated with reasonable ease and meaningfulness in terms of time response. The general arrangement for the test is shown in Fig. 1. There are two obvious factors that limit the accuracy of the final value of 1.56 sec for the system response time. The withdrawal time of the cadmium shutter is unknown since it was done manually. However, the shutter was light in weight and was required to move only 4–5 in., so withdrawal time is assumed as no greater than 0.05 sec.

The time mechanism was an Atomic Model-1030 scaler operated on 60 cycles. The statistical error involved in the device is ±0.017 sec. The closing and opening times of the auxiliary microswitches and relays used are not subtracted from the elapsed time since in most cases these values cancel themselves, and in any case are small.

The Beckman received a constant signal of half-scale on its 3×10^{-10}-ampere range before the step increase caused by shutter movement was applied. The higher signal was of a magnitude larger (~20%) than required to trip the circuit.

The sensitive relay was found to close in 0.65-sec when tested alone and full-scale current was applied. This time increases as much as 40% in moving the trip level from 80 to 90% of full scale.

The rod travel time and holding-latch opening time were measured compositely as 0.66 sec.

By difference between the total time of the system, 1.56 sec, and these times, the Beckman-ion-chamber-cable-response time was determined as 0.19 sec. The same ion chamber connected to each of two identical circuits gave response times differing by only 7%. Repetitive trials on an individual system resulted in maximum deviations of 2%.

Void Effects in Reflector

The reactivity contributions of two types of reflector voids have been investigated. The first, a direct beam hole on an extended radius of the sphere, increased the reactivity 0.046% when filled. This void was 2 in. in diameter and reached to within 1 in. of the sphere.

The second void, 1½-in. square and parallel to a core diameter, caused a reactivity change of 0.060% when located 3 in. from the core surface. This reactivity value decreased by a factor of two with an additional inch of displacement away from the core. The void penetrated the reflector to a depth equal to the far side of the core vessel.

Routine Operation

Routine operation of a general-purpose research reactor is impossible to attain because of the nature of work performed with the machine. However, it is highly desirable to standardize as much of the operation as possible. Two things are accomplished immediately upon standardization of any regular task: (a) the probability of inadvertently overlooking the task is minimized, and (b) more time is made available to those responsible for the reactor to consider the problems unique to the day's operation. A properly composed log book with complete checklists is a very valuable means for achieving the maximum standardization of operation.

The startup checklist will vary widely between reactors. In the case of the LRL reactor, a normal startup involves 41 preparatory operations by the operator. This increases to 44 on every tenth run, and 52 on every twentieth run—the less-important items are checked less frequently. This checklist requires 15 minutes for an experienced operator to complete.

An interim checklist is employed before startup is attempted after interrupted operation, and cannot be underestimated in importance. For the LRL reactor this list has only five items, but assures that the low-level power instrumentation has been reactivated. A temporary shutdown is invariably accompanied by a certain amount of confusion, and it is at such time that standardization of sequence is invaluable.

The shutdown checklist can be completed in 5 minutes and is followed only to insure that the reactor is secured and that equipment and instrumentation that have a relatively short lifetime are not left in operation. The logbook is arranged to provide for orderly entry of all information pertinent to the days operation (experiment descriptions, reactivity changes predicted, personnel list, run duration, power level, special instructions to operator, etc.) and a section for the chronological reporting of the instrument readings during the run. These readings are recorded every 30 minutes.

* * *

The authors regret that space limitations do not permit full and complete acknowledgement of all those who contributed to the operational investigations of the LRL reactor. The efforts of the following persons were of particular value. E. J. Strain, W. E. Drummond, D. C. Blair and W. K. Burns assisted in planning and executing the experiments. T. C. Dunckel and J. A. Atkinson operated the reactor. North American Aviation, Inc., manufactured the reactor. The work was sponsored by the U. S. Atomic Energy Commission.

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Locating Compton Edges and Backscatter Peaks in Scintillation Spectra

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In a scintillation spectrum, each photopeak is accompanied by a characteristic Compton distribution and a backscatter peak. Figure 1 shows these features in the pulse-height distribution of 0.51-Mev annihilation radiation, obtained with a cylindrical 1½ × 1-in. NaI(Tl) crystal. This article reviews the behavior of these characteristic features.

Compton Edge

The Compton edge corresponds to the maximum energy that an incident photon can impart to an electron in the scintillation crystal by Compton scattering. If the scattered photon escapes from the crystal, a pulse is obtained whose height corresponds to the energy received by the electron in this process. The energy of the Compton edge, $\hat{E}_{Comp}$, for an incident photon of energy E_γ is given by

$$\hat{E}_{Comp} = E_\gamma \Big/ \left(1 + \frac{mc^2}{2E_\gamma}\right)$$

Backscatter Peak

The backscatter peak is due to scattered photons from Compton processes in the material surrounding the scintillation crystal, mainly in the glass layers between the crystal and the cathode of the photomultiplier tube. After undergoing Compton scattering through 180 deg, an incident photon of energy E_γ will be left with an energy $E_{bac} = E_\gamma - \hat{E}_{Comp}$. This is the energy of the backscatter peak.

Analyzing Spectra

In the analysis of complex scintillation spectra, care must be taken to identify backscatter peaks and Compton electron distributions and to avoid confusing these with photoelectron peaks. If the energy of the incident gamma-ray is known, the backscatter peak often provides a useful additional calibration point. Repeated calculation of Compton-edge and backscatter energies can be avoided by use of Fig. 2, which gives these quantities for incident gammas up to 2 Mev.

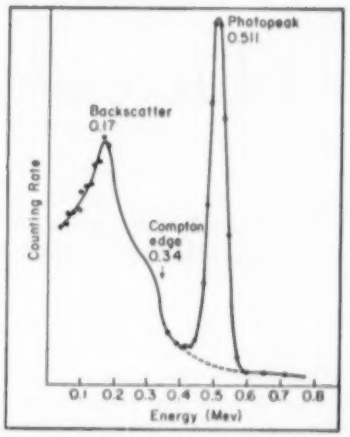


FIG. 1. Scintillation spectrum of 0.511-Mev annihilation radiation

The Compton edge is more prominent in the spectrum of high-energy gamma rays since the cross section for Compton scattering decreases more slowly with energy than the cross section for the production of photoelectrons, and the escape probability for scattered photons is larger. On the other hand, the backscatter peak becomes less noticeable as the incident gamma energy increases: with increasing energy, the total Compton cross-section decreases, and the angular distribution of the secondary photons from Compton events becomes more peaked in the forward direction, so that backscattering becomes less.

With larger scintillation crystals, the Compton edge becomes less pronounced since the escape probability for scattered photons is reduced. The backscatter peak does not decrease with larger crystals; however, the effect can be diminished by the use of a crystal container of low atomic number and a thin glass cover. The number of Compton events in the photomultiplier face can be reduced drastically by allowing the radiation to enter the crystal parallel to the tube face.

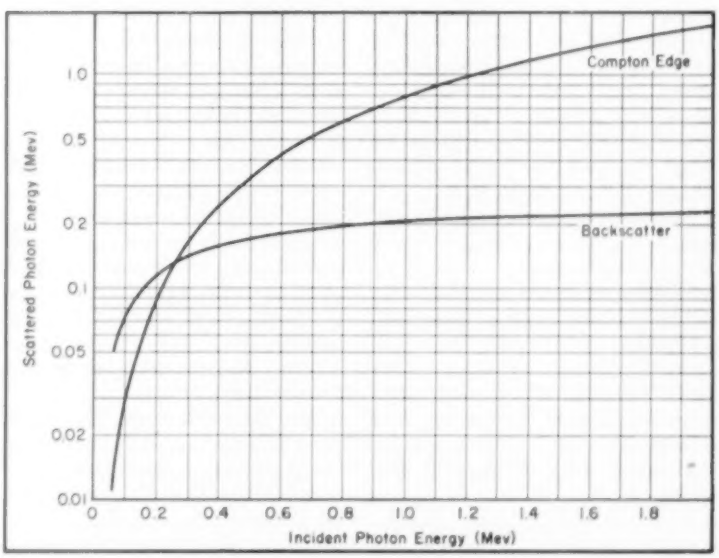
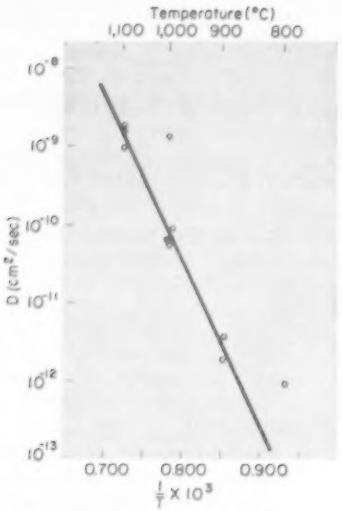


FIG. 2. Compton-edge and backscatter energies vs incident photon energy

* This work was supported by the National Science Foundation.

Ceramics— Versatile Nuclear Materials

Where will they serve the nuclear field—as reactor materials, waste disposal, in fuel elements?



Xe^{133} diffusion in MgO-Ni cermet

WITH CHEAPER NUCLEAR POWER as the motivation, reactor designers must strive for higher thermal efficiencies. For reactor-core temperatures of 2,000–3,000° F, as envisaged for gas-cooled reactors coupled to gas turbines (NU, March '56, p. 42), ceramics offer more long-range promise than do metals.

Although there are still serious problems to overcome before ceramics can be used under such critical core conditions, they are now being used or are near to use in other nuclear applications. Two such are as a refractory material for melting and casting nuclear fuels and as a medium for permanent radioactive waste disposal. Ideas on ceramics' role in nucleonics given at a symposium conducted by the American Ceramic Society in New York, April 25, are summarized here.

Reactor Materials

Ceramics provide the refractory nature sometimes wanted for structural materials in the reactor core, moderator, and reflector—as well as special nuclear properties, e.g., the very high thermal-neutron-capture cross section of boron and very favorable moderation properties of beryllium in ceramic compounds. However, several problems must still be solved:

1. Ceramics are generally brittle.
2. They are susceptible to high-temperature thermal stress and shock.
3. Most ceramics are more sensitive to radiation damage than are metals.

Solutions to these problems might be arrived at by developing new materials or fabrication techniques. However, J. R. Johnson (Minnesota Mining and Mfg. Co.) suggests that there should be more emphasis on adapting reactor design to the available materials.

Radiation damage. Radiation-induced lattice disorders and their effects on the properties of nonmetals were discussed by J. H. Crawford, Jr. (ORNL).

Energetic particles cause defects in two ways: (a) elastic collisions displace atoms from normal lattice positions into interstices, and (b) ionization through charge interaction may result in trapped charges in ceramics.

As a result of these lattice disorders, not only are strength properties harmed, but thermal conductivity decreases with exposure. Nearly all of the electronic properties are altered by charges trapped in lattice defects. Since diffusion in solids depends largely on the motion of defects, bombardment increases the diffusion coefficient of the constituent atoms.

Radiation sensitivity is related to the stability of lattice defects. Nonmetallic covalent crystals, with their rigid covalent structure, suffer much heavier damage than do metallic ionic structures—relaxation of binding forces to accommodate a displaced atom requires a large activation energy. Besides binding character, anisotropic lattice types, such as boron nitride and graphite, have interstitial voids that are available for trapping displaced atoms. This distorts the structure, affecting mechanical properties.

Experience with graphite indicates that the best results with anisotropic materials will be obtained with small particle size and a minimum of preferred orientation. Also, at higher service temperatures the damage is annealed to some extent.

G. E. Klein (ORNL) reported on X-ray diffractometer patterns of ceramic disks subjected to 2×10^{20} neutrons/cm². No changes from the unirradiated pattern were detected for single-crystal and hot-pressed Al_2O_3, spinel, forsterite, porcelain, steatite, and TiO_2. Al_2O_3 exhibited no change in thermal conductivity; however, changes (k/k_0—irradiated to unirradiated conductivity ratios) for the others were 0.6, 0.2, 0.5, and 0.6, respectively. Other ceramics are listed in the table.

Diffusion of Xe^{133} through MgO-Ni cermet. Knowledge of the rate of diffusion of fission products through reactor materials is important for predicting how long the reactor can operate without spreading contamination. W. E. Moody, Jr., W. D. Whitehead, and W. W. Kriegel (North Carolina State College) reported on Xe^{133} diffusion through a MgO-Ni cermet.

The Xe^{133} was produced by irradiating UO_2 in a reactor at 150° C. The UO_2 formed the core of disks made from 66% Ni-34% MgO cermet. The specimens were sealed in quartz glass and heated at 800–1,100° C to determine diffusion rates by Fick's first law of

diffusion. Xe^{133} was measured with a γ-ray spectrometer. The activation energy for diffusion was determined to be 4.4 ev with the diffusion coefficient given by

$$D = 1.85 \times 10^7 e^{-\frac{4.4\ ev}{kT}}$$

The curve shows the results.

The mechanism of diffusion appeared to be of the atom and vacancy interchange type and probably occurred along grain boundaries.

Boron compounds. Although the thermal-neutron-capture cross sections of boron and cadmium are 750 and 3,100 barns, respectively, boron is superior to cadmium as a neutron absorber on a volume basis and more than twice as efficient on a weight basis. Thus borides offer advantages where weight and space are important factors. G. R. Finlay (Norton Co.) described several boron compounds suitable for reactor use.

Boron carbide (B_4C, 78.3% B) has been used in control rods—usually as a powder in a stainless-steel tube. For shielding, the carbide can be used hot-pressed, cold pressed and sintered, bonded with sodium silicate, as boric oxide, pitch, or as resins. Polyethylene sheet containing up to 74% B_4C by weight has been used for wrapping pipes. Boron carbide has been incorporated in rubber and sheet aluminum (boral) and deposited on metal surfaces.

Boron nitride (BN, 42% B) is an excellent refractory with low thermal and electrical conductivity. In the absence of oxygen, a gradient of 2,000° C has been held through only 1 in. of the nitride.

Other borides are available. TiB_2 and ZrB_2 are excellent electrical conductors.

Beryllium compounds. Beryllium refractories have desirable properties for high-temperature neutron moderation and reflection—good corrosion resistance, adequate strength, and high thermal conductivity. However, as pointed out by W. W. Beaver and R. E. Long (Brush Beryllium Co.), optimizing these properties depends on high density. Difficulties in economically fabricating high-density BeO to precise reactor tolerances have limited its use. C. Hyde, J. F. Quirk, and W. H. Duckworth (Battelle Memorial Institute) suggest that refined experiments are needed to determine the characteristics of the starting materials significant for developing easily fabricated BeO ceramics.

Beaver and Long said further that renewed interest in gas-cooled reactors may stimulate work on BeO moderator cores (see NU, March '56, p. 33). Hot-pressed BeO as moderator-reflector could cut the fuel investment in half compared with using graphite.

Recent work reported in the Soviet Union, according to Beaver and Long, indicates that beryllium borides have very low densities and high melting points. They may find use in light high-temperature shielding or control rods.

Ceramics for Waste Disposal

For permanent disposal of high-level (>2 r/hr) reactor wastes, fixation in ceramics is receiving much attention. An unleachable mass avoids the potential danger of leakage inherent in the current practice of underground-tank storage.

Different approaches being made to ceramic fixation were outlined by J. M. Warde, *et al.* (ORNL).

Brookhaven National Laboratory—fixation on fired montmorillonite clay (NU, Dec. '55, p. 27). Wastes from processing spent U-Al or U-Al-Zr fuel elements are concentrated by evaporation and the Al and Zr are converted to the stable oxides. Fission products leached from the oxides are adsorbed in the clay and fixed by firing; unleachable fission products are safely disposed of with the oxides.

Oak Ridge National Laboratory—slurry of liquid waste and clay is dried and fired. Limestone or dolomite is added to liquid waste, e.g., from processing Al-clad uranium fuel, to form a slurry of aluminum hydroxide; shale and soda ash are added. Firing at 900° C forms a ceramic mass. Self-sintering by the heat of radioactive decay is being investigated.

Johns Hopkins University—firing alumina-silica gel. Radioactive waste is absorbed in gel, which is then fired to leach-resistant mineral.

British Atomic Energy Research Establishment—adsorption on ceramics and firing. Natural montmorillonitic green sands and montmorillonite clays are being investigated.

Effects on Ceramics Irradiated with 2×10^{20} n/cm²

Ceramic	*X-ray diffraction pattern*	*Thermal conductivity* (k/k_0)*
Silica glass	Halo broadening	1
ZrO_2	0.28% expansion in a_0	0.75
Zircon	No lines detectable; large loss in crystallinity	0.2
BeO	0.3% expansion in c_0; none in a_0	1
Cordierite	Line broadening	0.37

*Conductivity values obtained from ORNL-1852 (1955).

Molds and Crucibles

Ceramic refractories used for melting and casting uranium and other metals at Los Alamos Scientific Laboratory were described by S. D. Stoddard and W. T. Harper.

Magnesium oxide is considered their "universal" refractory. It is used for melting uranium and its alloys, nickel, cobalt, and their alloys and as a mold material.

Calcium oxide is used as a crucible material for ultra-pure uranium. Lower silica content than is obtainable with magnesia results in less silicon pick-up by uranium. Calcia is also easily separated from the melt due to its ease of solution. However, since calcia hydrates easily, it must be kept free from moisture.

Thorium oxide has been used for melting uranium-thorium oxide. It is not wet by molten zirconium, thorium, uranium, iron-uranium alloys, and pure iron in vacuum. Because of its density and high price, a method has been developed for lining alumina crucibles with thoria.

Aluminum oxide has been used as boats for tube furnaces and as crucibles for melting cobalt and other metals, in addition to its use in coatings and furnace refractories.

Crucibles for miscellaneous applications have been fabricated from zircon, zirconia, and the oxides of chromium, nickel, uranium, titanium, and the rare earths.

Many molds for vacuum-casting uranium and uranium alloys are electrode-type graphite. Since the molten metal tends to pick up carbon, mold coatings have been developed. Coatings of MgO, Al_2O_3-SiO_2, and magnesium zirconate produce castings having better surfaces than uncoated molds. Also, coated molds can be reused.

FIG. 1. Typical plant for separating U, Pu, and fission products from spent reactor fuel. This plant is at Hanford, Wash., works

Process Engineering at the Hanford Separation Plants

By CHARLES A. ROHRMANN
Separations Design & Development, Hanford Atomic Products Operation, Richland, Washington

SEMIFINAL AND CRUCIAL STEP in plutonium production—after fabrication of uranium metal, irradiation in reactors for transmutation to Pu, and aging, and before final preparation for shipment—is the separation of U, Pu, and fission products from each other. Purification requirements are extremely rigid: the radioactive fission products that exist in amounts measured in parts per million must be reduced to levels of parts per 10^{13}; because of its biological toxicity the Pu must be reduced to levels of 0.1 ppm. And the recovered U, still rich in U^{235}, subsequently must be processed by normal industrial techniques, including manual handling.

Economic considerations favor the continuous solvent-extraction processes over batch processing based on precipitation or scavenging techniques. Batch processing, generally more costly in industry, is unusually high for the processes employed in Pu handling because of the costly raw materials used and the large volumes of wastes for which costly storage facilities must be provided.

For protection from radiation, there are several feet of reinforced concrete between the separations-process equipment and the operators. Crane operators are enclosed in a heavily shielded cab, which in turn runs behind a thick concrete wall to prevent direct line-of-sight viewing of process equipment; all viewing of equipment and manipulating devices is by periscope.

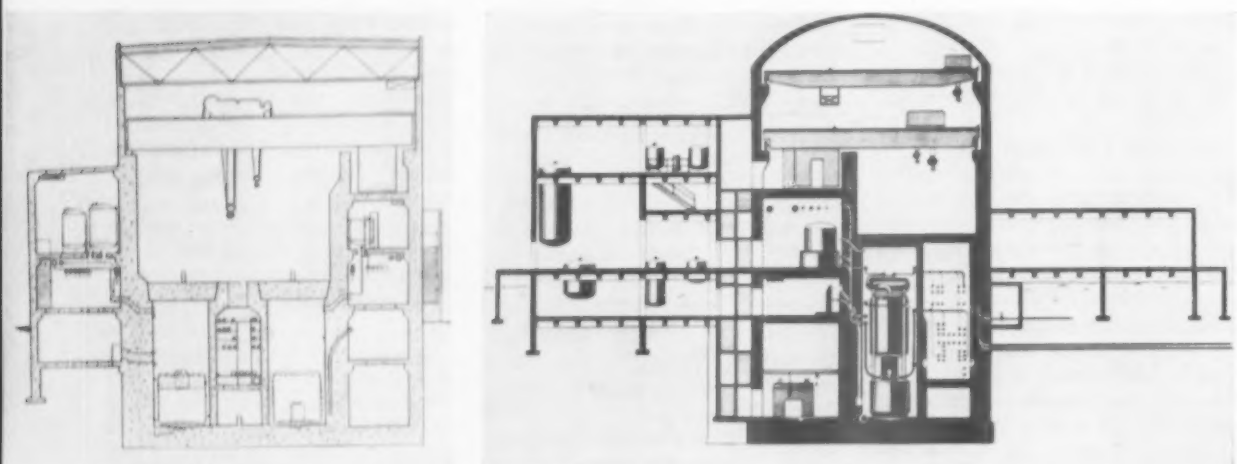


FIG. 2. Comparison of two plants arrangements. One at left has equipment cells on either side of pipe-tunnel—note crane cab behind shielding wall, tight fit of large equipment in cells, bends in the service piping to prevent direct beam of radiation from entering any operating area. Plant at right has equipment on only one side of pipe-tunnel, permitting simplification by having control gallery on only one side

FIG. 3. Gross corrosion in heat-transfer pipe section: this pipe, here supported by one finger, originally weighed 70 lb

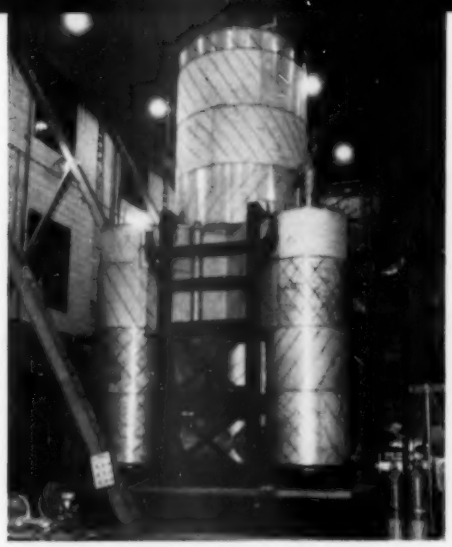


FIG. 4. Large evaporator for concentrating acidic solutions containing all waste fission products

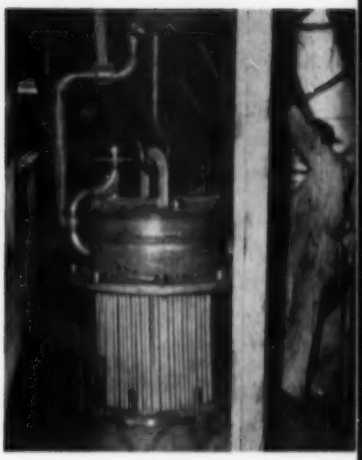
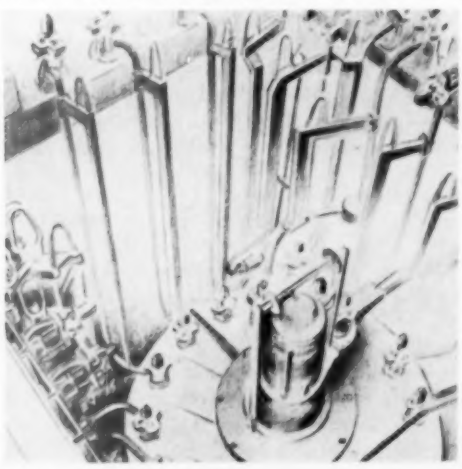


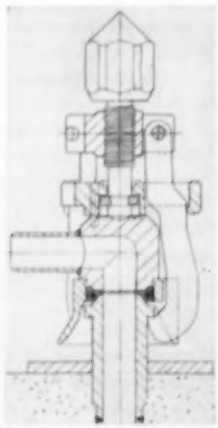
FIG. 5. Tube bundle being lowered into evaporator. Note small number of bolts, to save time in bolting up by remote crane

Equipment to carry out a certain step of a process is contained in an enclosure or cell separate from other equipment. In case of failure or malfunction, this segregation confines radioactivity to a relatively small part of the plant, where concentrated maintenance effort can be exerted with minimum concern for spread of radioactive contamination. Arrangement of equipment is in a straight line (the plants' relatively great length, together with massive trench-like appearance with concrete interiors has given rise to their being called canyons). Flow of process fluids between equipment cells is via a completely shielded pipe tunnel. The cells may be all on one side of the pipe tunnel in a long building (Fig. 2 right); or on both sides of the pipe tunnel in a shorter one (Fig. 2 left); the former permits operations and controls to be conducted from only one side of the building while the latter type of layout requires operation and controls on both sides but permits the entire building to be shorter.

Removable concrete-block lids close all equipment cells except when irradiated U is first brought into the plant for processing, and during maintenance or nonroutine inspection operations. All process equipment—reaction vessels, centrifuges, pumps, agitators, evaporators, control valves, liquid-liquid contactors and rotameters carrying radioactive solutions—are assembled, connected, and disconnected by manipulation from the crane. All such equipment is

FIG. 6. Process vessel in a cell, showing variety of jumpers attached; sketch indicates complexity resulting from need for remote operation





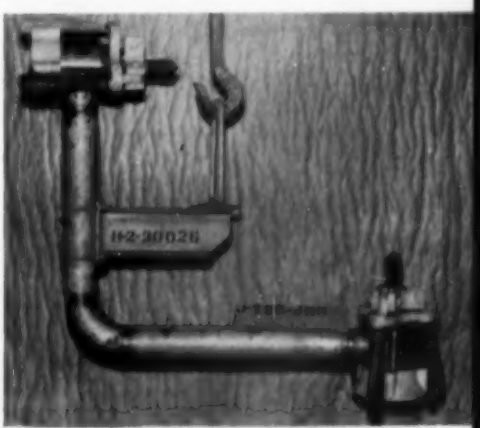


FIG. 7. Remote connector (left) and an assembly of piece of pipe with remote connector at each end—called a "jumper" (right). Connector heads fasten jumper tightly to wall nozzle and corresponding vessel nozzle by means of single nut

FIG. 8. Outdoor pit-type cell, used when a required processing improvement cannot be accommodated inside the canyon. Mobile crane is used for maintenance; instead of periscopes, mirrors and direct viewing at a distance are used to direct it. Remote connectors and jumpers are provided as in in-canyon cells. Here a jumper change is being made in a waste diversion box

accurately positioned in the cell with respect to adjacent equipment and to wall nozzles that connect to all the required services for each piece of equipment. The hook-ups for delivery of chemicals, power for agitators and pumps, air, steam, and water, as well as for instrumentation such as thermocouples, pressure-sensing devices, liquid-level and specific gravity measuring equipment, audio equipment and lubrication for moving parts are all made by means of the remote connector and the "jumper" (Fig. 7)—a pipe having a remote connector at each end. By means of a single nut on each connector, the crane operator can swiftly fasten a jumper tightly to a wall nozzle and a corresponding vessel nozzle. Standardization of vessel dimensions and orientation with respect to the wall-nozzle pattern allows a single jumper design to serve in a number of positions in the canyon. The jumper is balanced by counter-weights and positioning of the lifting bail so that it can be crane-lifted and lowered precisely into position to engage the required nozzles; some jumpers have three heads that must be engaged. For ease in maintenance, stacking or crossing-over of jumpers is avoided wherever possible. Prior to installation in the plant, all vessels, process equipment and jumpers are assembled in a "mockup shop" to check mechanical fit; thus tolerance discrepancies can be corrected prior to installation in the plants.

Working in a Canyon

Strong floodlights are installed on the cranes to assist in observations by the operator peering through his monocular periscope. Furthermore, space microphones enable the mechanic to hear what he is doing, e.g. when his automatic wrench contacts the object nut. Nuts and other parts temporarily removed can be stored on a tool board; special retaining springs hold each nut in the wrench until it is fastened or placed on the tool board.

Maintenance by Crane

The crane, with its single operator, performs all maintenance that can be done on all equipment in contact with radioactive materials. But the extent of such maintenance is quite limited; most such work involves replacing defective parts. Components to be repaired are transported elsewhere, and essentially no disassembly and assembly of repaired equipment is done in the separations plant. By far the largest portion of the operating time of the crane is in charging dissolvers with irradiated uranium to be processed.

Maintenance on the crane itself is done manually at one end of the canyon away from the process area; yet, because crane parts become contaminated from cell equipment with which they come in contact, the work may have to be conducted with a large number of men working under radiation exposure time-limits, sometimes as short as one minute. Every precaution is taken against the possibility of a crane breakdown preventing it from reaching its maintenance area.

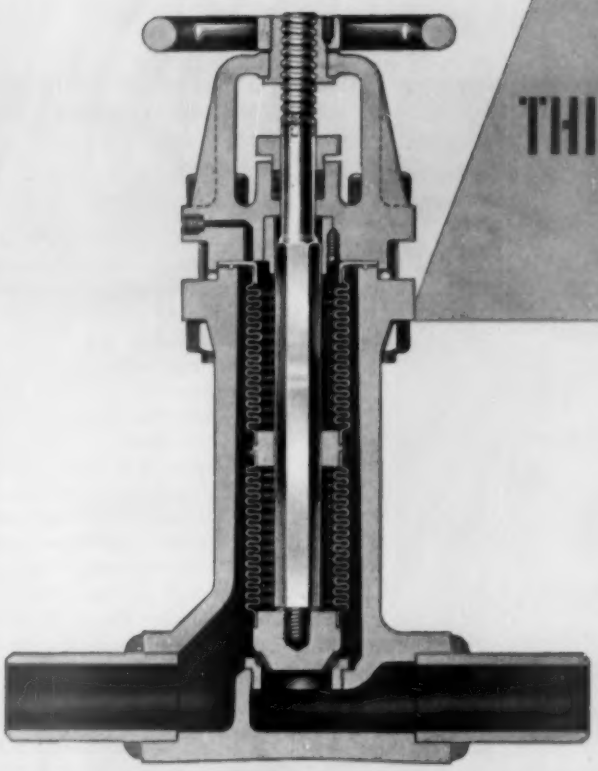
Preventing Failures

There have been many cases of mechanical failure of pump and agitator moving parts, and malfunctioning of jets, valves and rotameters. Because of the intensive radioactive contamination, most of this equipment is discarded and replaced with new. One separations plant was long plagued by frequent failure of heating coils in an evaporator used to concentrate acidic solutions containing substantially all the waste fission products; some of this vital equipment lasted as little as three months. The heating coils were built integrally into the vessel and their failure necessitated discard of the whole assembly. After a particularly rapid and unexpected failure, an intensive decontamination effort made close inspection possible. This revealed a surprising example of gross, uniform corrosion; a 26-ft section of 1½-in. stainless-steel pipe that should have weighed 70 lb could be supported on one finger (Fig. 3). Change to another type of stainless and improved specifications helped solve the problem, but most important, the evaporator was redesigned with removable heat-transfer surfaces that can be replaced by crane (Fig. 5); the tube bundles are provided in pairs so that production continues if one set fails.

Failed equipment that is contaminated is disposed of by burial (NU, May '55, p. 32).

Ventilation

An extensive ventilation system is required to prevent radioactively contaminated fumes and dusts from drifting into personnel areas of the plant or escaping to plant environs. An exhaust system keeps the cells under reduced pressure with respect to the rest of the canyon. In turn, the vessels are maintained at pressures slightly lower than the cells. Air is drawn through the spaces between the cover blocks into the cells, from the cells into an air tunnel, through a sand or glass-wool filter, and are discharged from a tall stack. Gases evolved from the process vessels are drawn out and chemically treated to remove biologically-dangerous fission products before discharge to the atmosphere.



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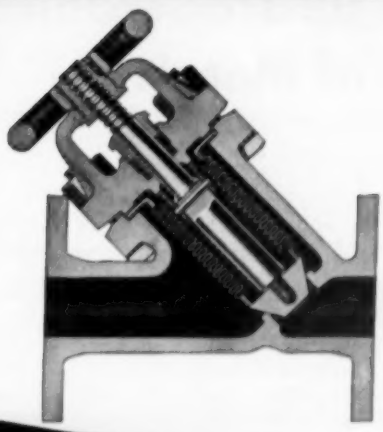

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IN ELECTRODECONTAMINATION, one electrical lead is clipped to object being cleaned and other lead to heated kettle containing foaming chemical solution

Electrodecontamination of Metals

By JOHN B. HUFF
Atomic Energy Division
Phillips Petroleum Company
Idaho Falls, Idaho

A process for electrocleaning steel alloys in alkaline solutions (*1*) is satisfactory, with some modification, for much of the metal decontamination at the Idaho chemical processing plant of the National Reactor Testing Station.

The electrocleaning process was adapted to electrodecontamination on a production scale, as most of the preliminary tests were made with radiocontaminated tools and plant equipment. Complete decontamination is usually not required—only to a point where repairs can be made and equipment returned to service.

Basic Process

The item to be decontaminated is suspended by an insulated link in a stainless-steel kettle of near-boiling sodium hydroxide solution (see figure). The work is made anodic by connecting it to the positive side of a high-amperage source of direct current. The stainless-steel kettle is used as the other electrode. High average current densities are used, as the evolution of oxygen from all surfaces is desirable. After 1-3 min the item is removed from the solution and rinsed with water. Wire brushing with the alkaline solution may be necessary at this point, especially if paint is being removed.

The work is then dipped in 2*N* sulfuric acid, and may be made anodic at a low current density. A smut usually appears on the surface at this stage and apparently carries radioactive particles. Most of it may be removed by wire brushing the acid-wet surface. The work is then rinsed in water and dried with rags or tissue.

Discussion

The process is subject to much variation—a-c or d-c current might be used, the work might be anodic or cathodic, and the electrolyte could be acidic, basic, or a neutral salt.

Nature of contaminants. Before choosing a trial process, it seemed necessary to consider the nature of contamination at this plant.

Dissolver product is probably a representative source of radiocontaminant. It is a nitric-acid solution of irradiated uranium fuel elements that have aged after removal from the reactor. Thus, the fission-product metals producing beta-gamma emissions should be present as metal-nitrate molecules or as positive ions.

Rubbing or burnishing a contaminated metal with a hard or soft substance might entrap contaminants so that they could be removed only with great difficulty. Since the wavelength of visible light is some thousand times the estimated diameter of the radioactive molecules, optical smoothness does not necessarily affect contamination factors. Thus, mechanical surface treatment was withheld from the first step of the process.

Removal of organic films. It would seem desirable in the first step of a decontamination process to completely remove organic films and the entrained radiocontaminants.

The anodic treatment in hot alkaline solution has proven very effective for this step. The oxygen evolved hastens the process by loosening scale and perhaps by chemical attack on some organic substances as well. Dislodged particles with positive charges are repelled by the anode; thus it is good practice to let the current flow while the work is withdrawn from the electrolyte, if there is no danger of touching the cathode and causing a short circuit.

Current supply. Electric welding generators with 200 or 300 amperes capacity have been used for direct current supply in this work. Items having a surface area of 4 ft^2 have been successfully treated.

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W. R. Rhoads to Head Dawsonville Project, To Be Biggest of Its Type in Nation

Lockheed Aircraft Corp., wasting no time in the development of nuclear aircraft testing facilities at Dawsonville, announced Tuesday that W. R. Rhoads will head up the Dawsonville project.

Mr. Rhoads, who lives at 120 Osner Dr., NE., is chief staff engineer at Lockheed's Marietta plant now. He has been with Lockheed since 1941.

He will direct the work of the approximately 500 scientists, engineers and service personnel who will be employed at the Dawsonville site.

LOCKHEED AND the Air Force officially announced Monday night at a dinner at Gainesville that they intend to build a 10,000-acre, multi-million-dollar nuclear aircraft test site just southwest of Dawsonville (population, 350).

And, perhaps as significantly, Lockheed's top Georgia executive hinted that the actual manufacture of a nuclear-powered plane—perhaps the world's first—might take place at Lockheed's Marietta plant.

AND

there's more that can't be published—yet

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spots that draw less than average current, due to greater distance from the cathode, obstructions, or other factors. Heavy average current density is necessary to get the required evolution of gas within holes and other spots that are unfavorably situated. Average current densities of 100–150 amperes/ft² have been used with good results. The individual operator soon learns from experience the current setting and time interval that give the best results for a certain item. Welding cable and clamps were used to avoid points of high resistance in the circuit.

The current demand for a large object obviously would be excessive at a current density of 100 amperes/ft². Some experimental work was done with a fabric-covered stainless-steel cathode. This cathode was rectangular and about 4 × 6 in. It was dipped in electrolyte and used as a mop on vertical and horizontal surfaces that could not be submerged. Decontamination was satisfactory but the fabric was soon destroyed, and highly contaminated surfaces would reduce the allowable working time for the operator.

Cathodes covered with woven asbestos were resistant to the electrolyte and were used to remove radioactivity from within tubes. The asbestos served as a porous insulator to prevent a short circuit. It appears that large internal cylinder walls could be treated with a rectangular cathode held so that its edge would appear as a chord when viewed from the end of the cylinder. Rubber sheeting should be satisfactory for insulating the back and edges of such a cathode. In general, the current seeks the shortest path through the electrolyte, so that the factor of distance can be used to gain some concentration of current on large surfaces. It should be remembered that the hydrogen evolved is very explosive and must not be allowed to accumulate in confined spaces.

Sulfuric-acid pickling. The mechanical aspects of contamination indicate the desirability of bubble action originating at the surface or within crevices and moving outward. However, some residual contamination usually remains after electrolysis, which requires severe treatment for its removal. This indicates that some radiocontaminants are held by an electron exchange, or by some physical force that is not well known. This residual contamination was quantitatively removed from test spots on stainless-steel disks with a short pickling cycle

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Chemlon Yarn Packing Style C-30 is available in spool or coil form, in a wide range of sizes from ⅛" up. *Can be lubricated with Teflon suspensoid or various types of lubricants.*

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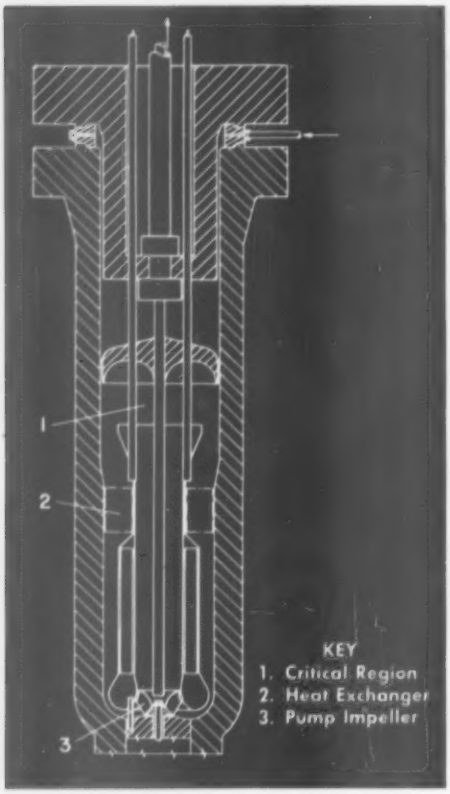

This simplified drawing of an experimental homogeneous type power reactor, now in the final assembly stage, shows one of five nuclear reactor projects currently under way at Los Alamos, where the world's first homogeneous reactor was designed and built and is still in operation.

Indicative of the importance of these experiments is the Laboratory's thirteen year record in active research, design and development in this major field of basic scientific interest.

Many challenging projects in nucleonics, physics, chemistry, metallurgy, mathematics and engineering support these as well as other of the Laboratory's diverse activities.

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in 2*N* sulfuric acid, followed by wir brushing.

The oxide coatings on stainless steels of the 18-8 groups are attacked by sulfuric acid. Test samples of type 347 stainless steel were quite rapidly dissolved in boiling 6*N* sulfuric acid. The amount of surface removed can be controlled by adjusting the time, temperature, and acid concentration of the pickling process. Excessive etching is obviously undesirable in most cases and can lead to hydrogen embrittlement of the parts.

This process leaves stainless steel in an activated condition, i.e., the chemically resistant oxide coating is partially or completely removed by the final acid dip. Stainless process equipment probably should be passivated before it is returned to service. This may be accomplished by nitric-acid treatments (*2*). Passivation might also be accomplished by anodic treatment in alkaline solution (*3*) that is free of radiocontaminants. Passivation studies on this project have been limited to some preliminary laboratory tests. If the original specification for a piece of equipment required that it be passivated, it would be necessary to include this step in the decontamination process. However, the oxide coating formed by stainless steel on exposure to air is adequate for most purposes.

Metals treated. Stainless and carbon steels were given primary consideration on this project, as their decontamination makes up the bulk of the work presented.

Stainless-steel mechanisms with lead shields (sample pigs) were processed as units with good practical results on both the lead and the stainless steel. No laboratory process was found for quantitatively decontaminating prepared samples of lead in the few preliminary tests made. Sample pigs having an initial contamination level of 30 r/hr have been reduced by a factor of 1,000 to 30 mr/hr, so that repairs could be made with a minimum of exposure to the mechanics.

No studies have been made with copper, brass, or aluminum. However, they have been put through the process as components of assembled machines. Aluminum reacts with the alkali, but on most parts some etching can be tolerated.

The difficulty of removing some radiocontaminants from a metal surface indicates their combination as complex oxides. Many of the common

metals form chromites, ferrites, plumbites, etc., which, as a group, tend to be insoluble in ordinary reagents. They are probably even less soluble in acid due to the galvanic couple between them and the parent metal. Pickling stainless steel might thus produce a series of infinitesimal buttes, with oxide crests that break loose under wire brushing. Thus, solutions chosen to dissolve the oxides present would be expected to remove more of the radioactive elements than an acid chosen to dissolve the metal.

Laboratory tests. The laboratory tests were made with sheet-lead or stainless-steel disks. They were cut $1\frac{15}{16}$ in. in diameter and cleaned with acetone. A retaining circle was drawn with a template and a wax pencil to have an internal diameter of $1\frac{15}{16}$ in. The disks were placed on a metal plate having leveling screws at the corners. Samples of diluted dissolver product were deposited within the wax retaining circles from a 1-ml pipette. The tip of the pipette was used to spread the sample if it did not cover the area within the circle. A heat lamp was used to evaporate the liquid.

The sample was then counted with an end-window G-M tube in a vertical lead pig. A shelf for the counter was fitted with two pins to serve as stops for the disks so that the same geometry would be obtained from sample to sample. Similar samples varied over a range of about 7% of the net counts per minute. The disks showed a net count in the order of 13,000 cpm for stainless steel and 17,000 cpm for lead. A clean stainless-steel disk was used as a cathode, which was mounted facing the test spot at a distance of about $\frac{1}{2}$ in. Current was supplied to the disks from a 6-volt storage battery with a fuse, switch, ammeter, and rheostat connected in series. The sample was counted at various stages of the test.

The liquid samples attacked the lead almost immediately and a salt residue was left after drying. Had the sample contained sulfuric rather than nitric acid, it is assumed that the stainless-steel disk would have been etched and that a new set of conditions would develop. Thus, some system of laboratory tests to measure the effectiveness of the various process steps is considered a necessary part of decontamination work at this time.

Alkaline electrolytes. In the early work on this project, the electrolyte used was sodium hydroxide solution made up at a concentration of six

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ounces of flake sodium hydroxide per gallon of water. This solution gave good results but the bursting of bubbles threw solution into the air, causing considerable discomfort to the operator, and indicating a potential source of air contamination.

By adding one ounce per gallon of laboratory Calgonite (glassy sodium phosphate), a foam is produced on the surface of the solution and hardly any airborne caustic is noticeable during electrolysis. Controlled foaming is important. If the foam is too heavy it overflows the kettle. Some adjustment of foaming agents might be required for different waters or special conditions. Good foaming characteristics were observed with a solution containing 4 oz sodium hydroxide, 2 oz sodium carbonate, and 2 oz trisodium phosphate per gallon of water. Higher alkali concentrations might prove better for removing heavy deposits of paint or grease.

A number of proprietary products are advertised for electrocleaning various metals. Wyandotte Chemical Corp., Wyandotte, Mich., and Oakite Products, Inc., 19 Rector St., New York 6, among others, advertise electrocleaning products.

Operational techniques. The decontamination room has a 25 × 45 ft stainless-steel floor with floor drains to the liquid-waste-treatment plant. The floor area is served by a hoist that will lift the hook about 15 ft above the floor. When working with high-level contamination, the area may be closed to foot traffic with little inconvenience to the rest of the plant. Good ventilation is provided, so that air-borne activity resulting from unwrapping contaminated items, for example, is quickly exhausted. Most of the vessels in use may be drained through valves to the liquid-waste plant; by avoiding unnecessary handling of spent solutions, floors and equipment are kept at lower levels of contamination.

Strong alkaline solutions rapidly attack asphalt tile, and concrete floors may be pitted by spilled acids. If floors of this type are used, they may be covered with paper.

Items such as sample pigs drip for some time after removal from solution. Sinks could be fitted between vessels, so that rinsing could be accomplished without diluting the solution.

Special plans generally should be made for handling items contaminated to levels above 30 r/hr, where simple operations, such as fastening a hook,

result in considerable exposure to the operator. Suggested preliminary procedures include making the room a shoe-cover area, covering the floor with paper, and selecting the necessary tackle with care. Special equipment for jobs where the allowable working time is short might include a tank or canal and some underwater tools. Exposure to the operator could also be reduced by remote crane controls.

Some chances of accidents to personnel have been observed, although the process is not considered particularly hazardous. The possibility of hydrogen explosion should be restated. The possibility of electric shock corresponds to that for welders. Rubber gloves and safety glasses are required equipment for protection against the solutions used. It appears possible that an individual could sustain an eye injury from the light of an accidental arc. Good hoisting practice, i.e., safe tackle, should be used, for equipment dropped into a boiling vat of solution could cause serious burns.

Since the new decontamination room was made available for use, one operator has taken care of all the work brought in from this plant, and some from outside plants also. Experience is apparently as necessary in decontamination as in electroplating, or any other art. For that reason it is better practice to employ and train a specialist than to permit each individual to decontaminate the tools and equipment he uses. Average exposure to the operator here has been about half the allowed 3,900 mrep per quarter. However, it appears that exposure rather than the work load could well be the limiting factor with this system.

This is a preliminary report on a process that obviously needs more testing. Some of the opinions expressed are based only on observations made in the course of the work, and are thus subject to correction.

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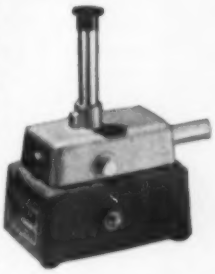

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RaD, RaE, and Po in the Atmosphere

By P. KING,* L. B. LOCKHART, Jr.,* R. A. BAUS,* R. L. PATTERSON, Jr.,* H. FRIEDMAN,† and I. H. BLIFFORD, Jr.†
Naval Research Laboratory
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At the time this research was undertaken, a survey of the literature revealed many references concerning the amounts of the short-lived RaB and ThB in the atmosphere, but no information on the quantities of the longer-lived RaD, RaE, and Po.‡ This dearth of information prompted us to install facilities at several naval bases in different parts of the world to collect natural radioactive products from the atmosphere for subsequent analysis at Washington, D. C.

These collections were made by either, or sometimes by both, of two methods. The first method used high-capacity air filter units with filter paper as the collecting medium. The second involved the collection of large volumes of rainwater (100–600 gal) and the concentration of the activity with aluminum hydroxide floc. As a result of the chemical methods used, the radioactivity from up to 1,000 gallons of rainwater or 10^6–10^7 ft³ of air could be concentrated readily on 50–100 mg of carrier. Counting of the separated β-activity gave a reasonably accurate measurement of the concentration of the long-lived products in the atmosphere. Qualitative estimates of the Po alpha activity were made.

Rain-Water Collection

Rain was collected on 500–1,000-ft² surfaces made of aluminum sheeting and was conveyed by aluminum gutters and pipes to aluminum collecting tanks. For some of the collections made at the Naval Research Laboratory, automatic controls diverted portions of the rain into three different tanks so as to compare the activities collected during different parts of the rain.

In many of the collections more rain

TABLE 1—Rainwater Collections Made at Washington, D. C.*

Date collected (1950)	*Volume collected (gal)*	*Pb fraction*		*Bi fraction*	
		β-activity (dpm)	*α-activity (dpm)*	*β-activity (dpm)*	*α-activity (dpm)*
Jan. 12–30	340	1,400	6	12,000	710
Mar. 31–Apr. 24	220	850	8	14,600	600
May 3–12	260	2,140	10	14,200	490

* Activity not corrected for decay, absorption, or backscattering.

TABLE 2—Distribution of RaE(Bi^{210}) Activity Among Rainwater Fractions Collected at Washington, D. C.

Date collected (1950)	*Rainfall (in.)*	*Volume collected (gal)*	*Insoluble residue (gm)*	*β-activity (dpm)**	*β-activity (dpm/gal)*			
					Tank A	*Tank B*	*Tank C*	*Total collection*
June 29		30	12.5	1,930	64			29
		60	2.9	1,740		29		
		150	1.4	3,200			21	
July 9		30	0.8	1,200	40			
		60	0.8	160		3		6
		225	2.4	450			2	
July 15–16		40	7.0	2,360	59			
	1.5	55	2.1	1,230		22		17
		300	0.9	3,080			10	
July 20		40	7.6	2,300	57			
	1.4	60	1.7	2,160		36		19
		300	1.7	3,240			11	
Aug. 19	4.8	40	25.0	1,700	43			
	(cont.)	60	3.6	1,080		18		13
		275	3.0	2,180			8	
Aug. 23	1.35	40	4.9	2,760	69			
	(2-hr	60	1.4	1,760		29		40
	rain)	275	2.0	10,640			39	
Sept. 11		40	5.3	250	6			
		115	3.0	790		7		9
		275	2.0	2,640			10	
Sept. 21		40	12.5	1,330	33			
	0.86	60	2.1	1,740		29		30
		275	2.1	8,250			30	
Oct. 8–9		40	7.6	1,280	32			
	0.54	60	3.5	950		16		12
		275	2.5	2,260			8	
Oct. 23		40	4.0	2,000	50			
	1.86	60	6.2	1,890		32		20
		275	3.0	3,400			12	
Nov. 20		40	5.3	2,220	56			
	0.55	60	13.7	1,640		27		22
		150	2.8	1,580			11	
				Average	46	22	15	20

* Activity of Bi_2O_3 fraction corrected to time of Pb-Bi separation.

* High Polymers Branch, Chemistry Div.
† Electron Optics Branch, Optics Div.
‡ Recently some information on the longer-lived activities in air has been reported (*1, 2*).

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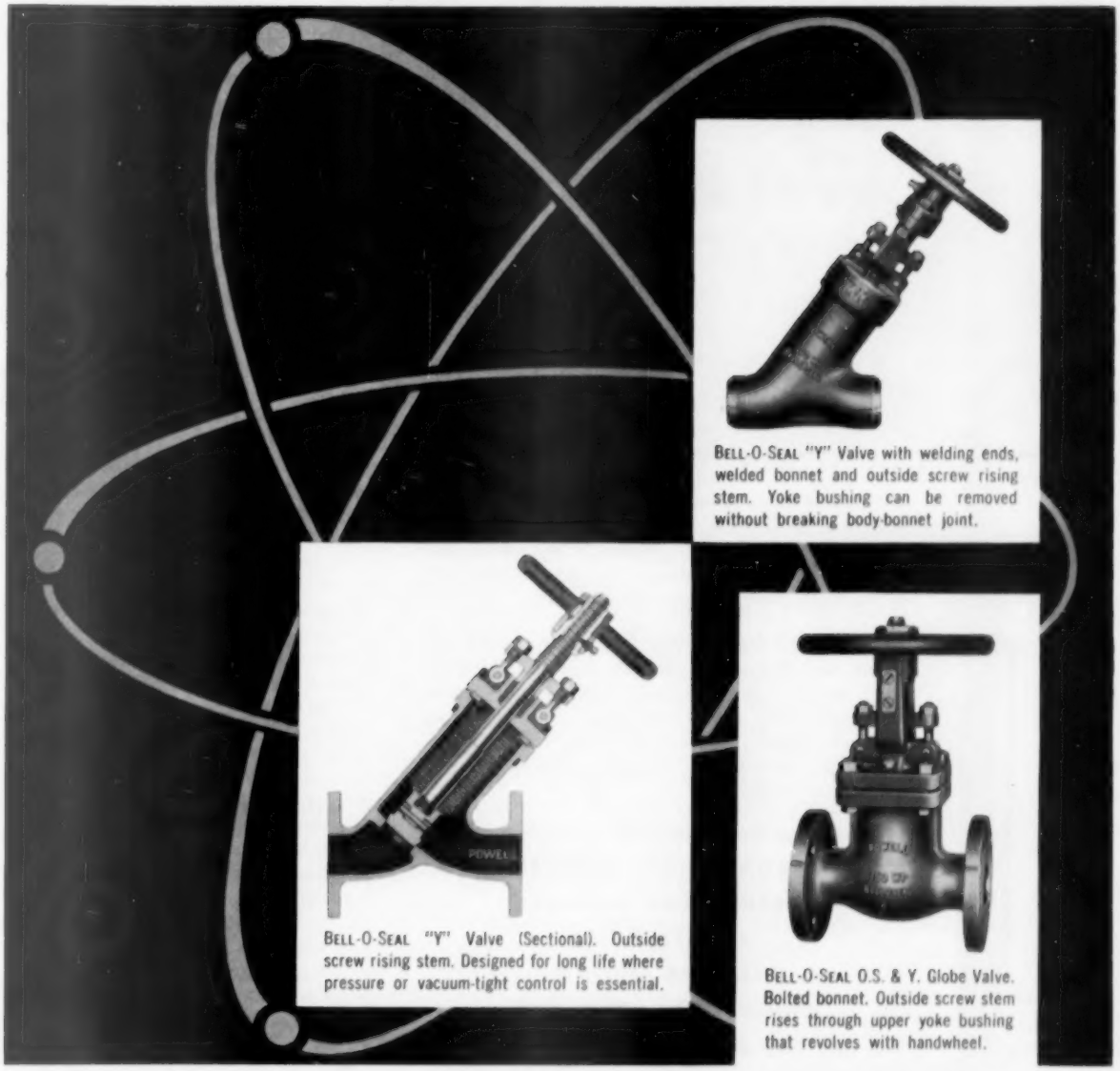

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fell than could be contained in the tanks and much was lost through overflow. The results are based on the water remaining in the tanks at the end of the collection period.

Flocculating procedure. The rainwater in the tanks was stirred with a jet of compressed air and a solution of aluminum sulfate was added to make the final concentration about 0.2 gm $Al_2(SO_4)_3 \cdot 18\ H_2O$ per gallon of water. The *p*H was adjusted to 7.0 ± 0.1 with a sodium carbonate solution using LaMotte standards with bromthymol blue indicator. Stirring was continued for 45–60 min and the treated water allowed to settle undisturbed overnight. After settling, the clear supernate was removed by syphoning and the $Al(OH)_3$ floc transferred to glass bottles for further settling and concentrating. The floc from 1,000 gal of water could generally be concentrated to a volume of 2–5 gal.

This procedure has been checked by adding 50–100 mg of soluble lead and bismuth salts to 100 gal of water and then collecting them with aluminum hydroxide floc as described above. At the concentrations used ($0.6–1.1 \times 10^{-6}$ mole/liter), recoveries were about 70–90%, including all losses due to separation of the floc and chemical separation of the material.

Chemical procedure. The floc samples were boiled with hydrochloric acid (1:4) and filtered from any insoluble residue. In some cases this residue was further treated with nitric, sulfuric, and hydrofluoric acids and analyzed separately. This treatment was discontinued when insignificant quantities of RaD, RaE, and Po activities were found to be associated with this material.

Carriers equivalent to about 75 mg each of Bi_2O_3 and $PbSO_4$ were added to the solutions and equilibrated with the radioisotopes. Standard procedures for separating bismuth and lead were used. The separated materials were redissolved and reprecipitated to improve the radiochemical purity.* The time of separation was noted and the samples ignited, weighed, and mounted on plastic planchets for counting. The counting rates obtained by use of standard techniques were converted to decomposition rates by applying appropriate geometry corrections.

Results. Some of the data resulting

* At times when fission-product activity is present in the sample, further radiochemical purification of these fractions is required.

from the analysis of a few rainwater samples collected at Washington, D. C., are shown in Table 1. The identity of the RaD (22-yr Pb^{210}) was established by following the rate of buildup of RaE (5-day Bi^{210}) in the lead fraction. The RaE contained in the bismuth fraction decayed with a 5-day half-life. Some α-activity due to Po^{210} was invariably found in the bismuth fractions. The separation of Po^{210} in carrier-free condition gave activities as high as 5,000 dpm from several collections; however, this procedure was not employed routinely since it gave only qualitative results.

A number of studies were made on the distribution of the RaD in different portions of the rain (Table 2). There seems to be no correlation between the concentration of activity in the sample and quantity of dirt, character of the rain, or time between rains. In general, however, the first portion of the rain contains the greatest amount of insoluble material and the highest concentration of activity.

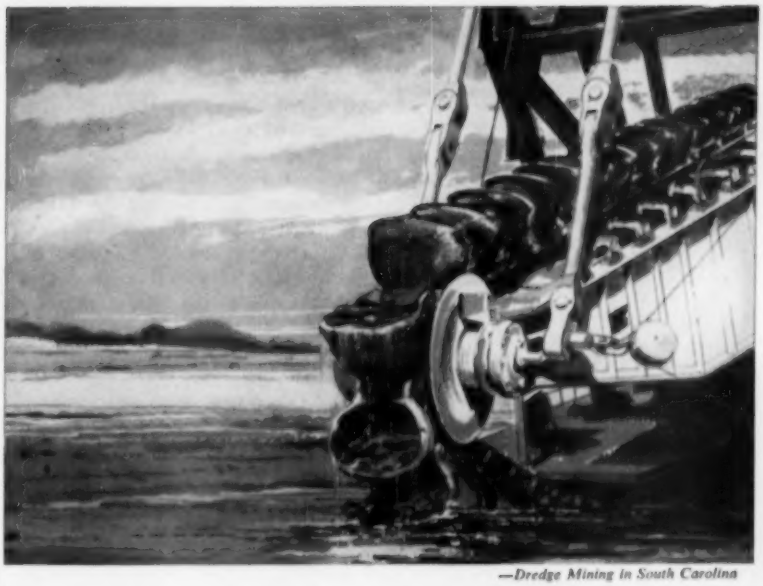
Collections of RaD activity made at a number of different sites are compared in Table 3. Some variations are to be noted at each site though they are not as great as the differences between collections at different locations. Rainwater collections from inland sites such as Glenview, Ill., and Washington, D. C., exhibit the highest concentration of activity; those on the coast (Panama) or on larger islands (Hawaii, Philippine Islands, Kodiak) show less activity, and the collection made on a relatively small land mass far removed from continental areas (Samoa) shows the least activity. All of the bismuth fractions that were checked showed some α-activity (Po^{210}).

Blower Collection

Air taken from outside was passed through a 400 in^2 filter paper (Army Chemical Corps Type 5) at about 2,000 ft^3/min and vented in such a manner that it was not drawn into the system again. At the end of the collection period the filter paper was removed and put into solution; the lead and bismuth were separated in the same manner as from the floc.

Chemical procedure. Filter-paper samples were dissolved by fuming with hot nitric-sulfuric acid mixtures to which a small quantity of hydrofluoric acid had been added. The remainder of the procedure was the same as for the rainwater samples.

Results. Results for the filter-paper



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collections (Table 4) were similar to those obtained with rain water. Only rough estimates of the volumes of air have been made since the quantity of dust picked up by the filter caused the flow-rate to decrease continuously.

As considerable time elapsed between the dates of collection at the various sites and analysis at Washington, D. C., the RaD-RaE equilibrium had been reestablished and RaE measurements were essentially the measurements of the RaD parent in the sample.

Conclusions

The presence of RaD and Po in the atmosphere suggests that a study of the ratio of these activities can lead to information relative to the lifetime of these materials in the atmosphere. It would be of interest to see how well such a determination would agree with the measured mean lifetime of about 15 days for RaD in the atmosphere as determined from comparisons of the short-lived radon decay products with RaD in the air (*1*). No attempt is made here to determine such a value since the Po determination was not made with sufficient accuracy.

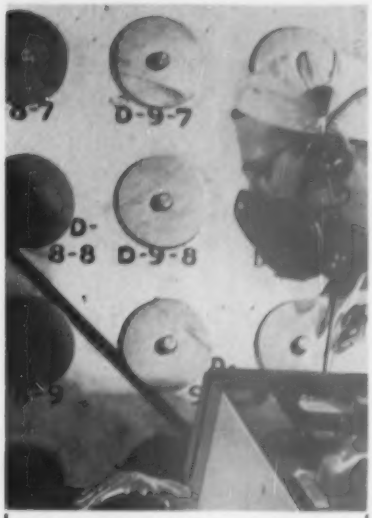
The results suggest several generalizations:

1. High-capacity air filters and rainwater collections effectively provide

TABLE 3—Distribution of RaE in Rainwater at Various Locations

Location, date collected (1950)	*Rainfall (in.)*	*Volume collected (gal)*	*Insoluble residue (gm)*	*Carrier recovery (%)*	*β-activity of Bi_2O_3 fraction†*		
					dpm	*dpm/gal*	*dpm/gal (avg)*
Glenview, Ill.							
Jan.		265	*	89	6,600	25	
Jun. 2–3	1.6 (squall)	564	38.9	95	13,100	23	
Jun. 24–30	Flash showers	563		76	13,700	24	
Jul. 6–19	1.23 (showers)	563	6.6	22	5,640	10	21
Panama							
Mar. 7–14	0.48	170	0.1	102	470	2.8	
Mar. 16–Apr. 24		250	0.8	96	2,270	9	
May 18–27	15.96 (continuous)	500	0.3	87	600	1.2	
Jun. 28–Jul. 20	10.78 (continuous)	500	*	101	1,920	3.8	
Jul. 20–Aug. 14	16.17 (continuous)	500	0.5	96	1,210	2.4	
Nov. 24–Dec. 15	20.27 (continuous)	500	4.5	79	1,070	2.1	
Jan. 5–Feb. 6 (51)	1.75 (showers)	500	*	83	1,130	2.3	3
Hawaii							
Mar. 8–Apr. 7	showers	400	*	107	1,310	3.3	
May 2–Jun. 12	showers	350	0.2	100	720	2.1	
Aug. 13–Sep. 18	showers	400	5.0	89	4,890	12	
Sep. 18–Dec. 11	continuous	300	16.7	90	5,340	18	9
Philippine Islands							
May 4–25	showers	270	*	152	2,090	8	
Jul. 4–Aug. 2	continuous	270	*	108	2,070	8	
Aug. 2–30	cont. for 2 wk	270	*	143	2,280	8	
Oct. 3–25	showers	270	*	94	3,060	11	
Oct. 30–Nov. 30	showers	270	3.4	94	3,000	11	9
Samoa							
Apr. 1–30	daily	400	96.5	204	2,960	7.4	
May 1–31	daily	400	*	106	330	0.8	
Jun. 1–30	daily	400	*	90	290	0.7	
Jul. 1–31	daily	400	0.7	92	460	1.1	
Aug. 1–31	daily	400	0.4	97	170	0.4	
Sep. 1–30	daily	400	4.5	95	1,010	2.5	2
Kodiak, Alaska							
Jun. 6–19	2.3 (scattered)	400	4.8	90	2,620	6.5	
Jun. 19–Jul. 5	3.3 (scattered)	500	1.7	107	2,300	4.6	
Jul. 7–17	1.9 (scattered)	500	6.8	100	1,550	3.1	
Sep. 11–25	7.6 (continuous)	500	1.0	89	3,450	6.9	
Oct. 23–Nov. 6	0.4 (scattered)	500	5.5	89	6,350	12.7	
Dec. 5–27	2.1 (scattered)	500	4.0	101	2,590	5.2	6.5

* Residues dissolved completely by wet ashings and fusions.
† Corrected to time of Pb-Bi separation.



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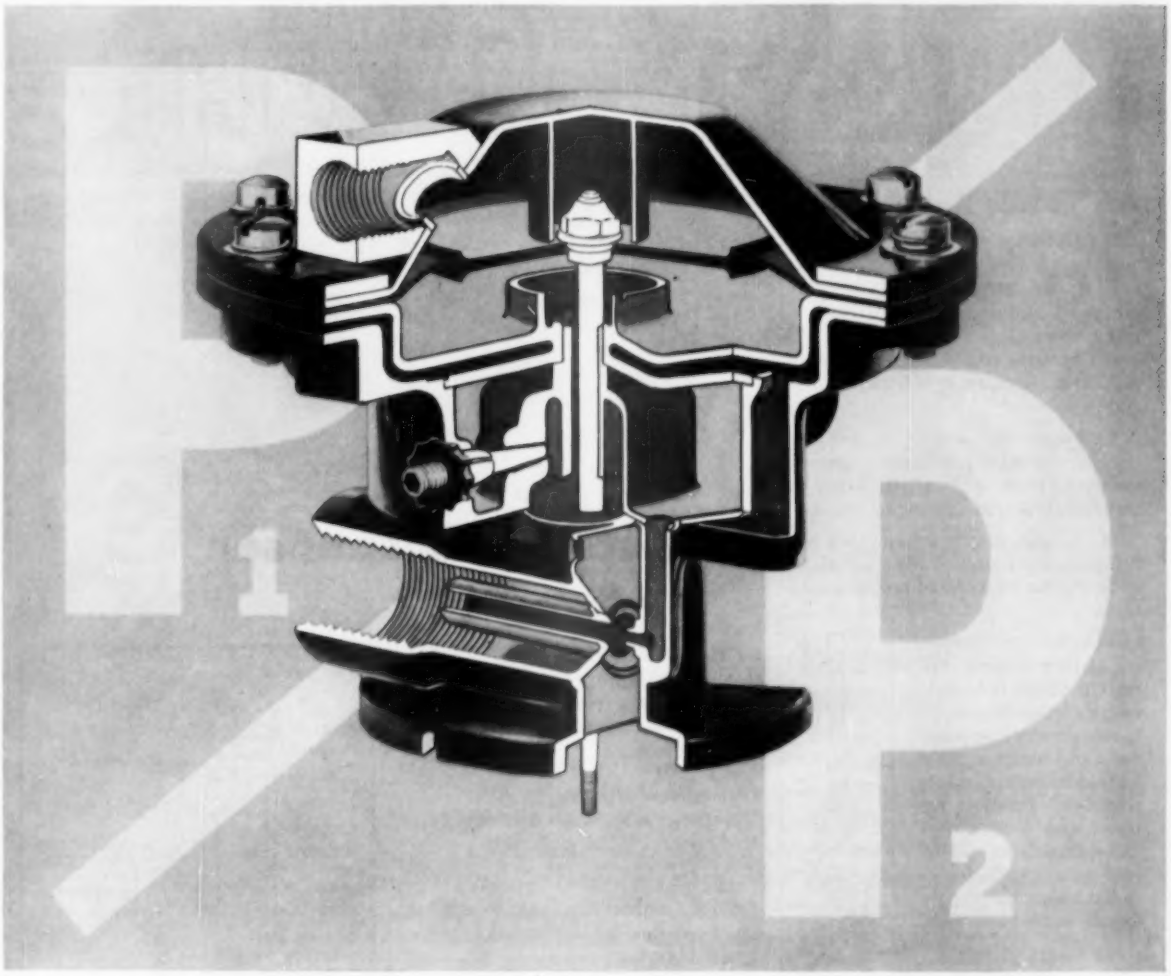

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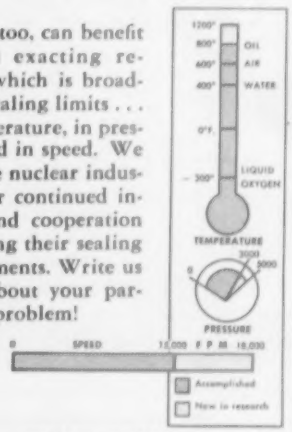

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TABLE 4—Filter-Paper Collections Made at Washington, D. C.*

Date collected (1950)	Volume processed (ft^3)	Pb fraction β-activity (dpm)	Pb fraction α-activity (dpm)	Bi fraction β-activity (dpm)	Bi fraction α-activity (dpm)
Mar. 1–31	2×10^7	1,960	2	4,770	4
Mar. 21–31	5×10^6	960	4	2,040	112
Mar. 21–Apr. 24	2.5×10^7†	90	2	1,210	34
Mar. 31–Apr. 24	2×10^7	410	8	8,510	274
Apr. 3–15	1.5×10^7			5,610	128

* Activity not corrected for decay, absorption or backscattering.
† Filter used as backing for Mar. 21–31 and Mar. 31–Apr. 24 collections.

large samples of airborne natural radioactive decay products.

2. The RaD activity collected by rain varies widely at different places and at different times at any given place. On the basis of present information, there seems to be no simple correlation of the quantity of activity collected with the character of the rain, the seasons, or the quantity of dirt present in the collection from rain.

3. The average RaD activity varied by a factor of 10 between island sites, e.g., Samoa, and inland locations, e.g., Washington, D. C.

BIBLIOGRAPHY

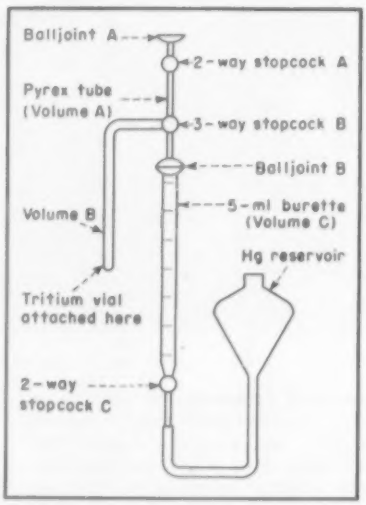
1. I. H. Blifford, L. B. Lockhart, Jr., H. B. Rosenstock. On the natural radioactivity in the air, *J. Geophys. Research* **57,** 499 (1952)
2. P. E. Damon, P. K. Kuroda, NUCLEONICS **11,** 59 (1953)

Tritium-Gas Dispenser

By JOHN A. BARTON and DANIEL PARRISH
Radioisotope Unit
Veterans Administration Hospital
Seattle, Washington
and
Department of Medicine
University of Washington School of Medicine
Seattle, Washington

Since the cost of tritium in uniform small amounts is somewhat prohibitive, a method is needed to deliver small and accurately known amounts of activity from a vial containing 50–100 millicuries. Such a method is described here.

Certain requirements must be met in the apparatus: (a) An all-glass system is preferable because of the porous nature of most other substances to tritium. (b) A method must be devised so that the pressure and volume of gas in the shipping vial need not be known. (c) It is desirable to maintain the purity of the tritium, which elimi-



TRITIUM BURETTE has three principal volumes—Pyrex tube (A), side arm (B), and burette (C). Rubber tube connecting stopcock C to reservoir never contacts tritium. Balljoint B permits attaching additional calibrated volume; ball joint A connects to chamber receiving tritium

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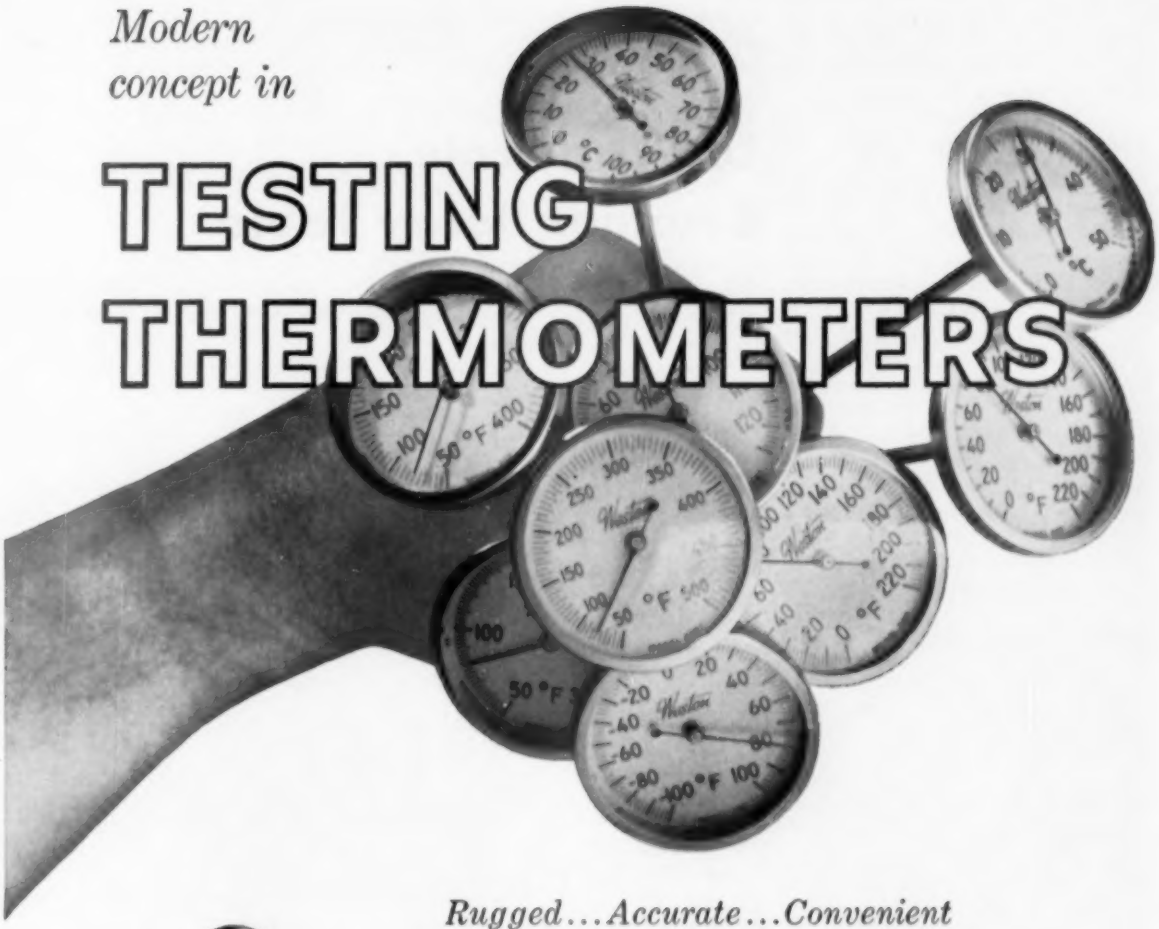

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nates any technique depending on air dilution.

These considerations led to an all-Pyrex device in which the delivered activity depends on the product of the initial activity and the ratio of two volumes. The essentials of the apparatus are shown in the diagram.

Delivery Procedure

After the vial has been broken by an enclosed iron weight and the tritium has expanded into the side arm, the total volume of the system, V_T, is adjusted by the burette mercury level. Stopcock C is closed and volumes A and C are evacuated. Stopcock A is then closed and stopcock B is turned so that the tritium may diffuse into the entire volume. After sufficient time has elapsed volume A is isolated and the tritium in volume C is transferred back into B by allowing the mercury to rise in C to the bottom of stopcock B. Then the tritium in A is transferred to the appropriate container by mercury displacement.

Activity Delivered

The amount of activity delivered depends upon the ratio V_A/V_T. Difficulty is encountered in the direct measurement of V_B prior to the delivery of all the tritium, but it can be shown that, for any given delivery, the amount of tritium obtained is given by

$$R_0 \frac{V_A}{V_T}\left(1 - \frac{V_A}{V_T}\right)^{n-1}$$

where n is the number of the delivery and R_0 is the initial activity. The quantity V_A/V_T can be evaluated by considering the ratio of any two successive deliveries, $k + 1$ and k

$$\frac{R_0 \frac{V_A}{V_T}\left(1 - \frac{V_A}{V_T}\right)^{k}}{R_0 \frac{V_A}{V_T}\left(1 - \frac{V_A}{V_T}\right)^{k-1}} = 1 - \frac{V_A}{V_T}$$

Any method of assaying the two deliveries will be satisfactory and one can write

$$1 - \frac{V_A}{V_T} = \frac{A_k + 1}{A_k}$$

where A_k and $A_k + 1$ are the two assays. Then

$$\frac{V_A}{V_T} = 1 - \frac{A_k + 1}{A_k}$$

The apparatus described here has been in constant use for several months, averaging about 5 deliveries per week. It is completely satisfactory both in accuracy and reproducibility. The system is flexible in that the volume ratio V_A/V_T can initially be chosen to deliver the approximate amount of activity, and the exact amount is obtained by the adjustment of the Hg level in volume C. In addition, the total volume can at any time be increased by inserting a calibrated volume in the space provided. Finally, if very small amounts of tritium are required, the system may be cascaded.

Log-Log Scale Becomes Decay Table

By R. HOBART ELLIS, Jr.
NUCLEONICS

The computation of radioactive decays is surprisingly simple with a log-log slide rule. Many modern rules have an LLO scale for numbers less than unity. If we place the 0.5 of such a scale opposite the half-life on the sliding scale, all of the other numbers of the LLO scale will represent the fractional decay that corresponds to the decay times represented by the numbers of the sliding scale.

As a simple example, consider a shipment of radioactive iodine that contained 100 mc on March 1 at 8:00 a. m. What is its activity at noon on March 18? The half-life is 8.14 days.

We place 8.14 of the sliding scale opposite 0.5 on the LLO scale (see Fig.) Opposite 17.17 (the decay time) on the sliding scale we find 0.232. Multiplying by 100 mc we find that the shipment contains 23.2 mc at the later time.

Why does it work? We are solving the decay equation, $n/n_0 = e^{-\lambda t}$, where: n = activity at time t, n_0 = activity at time zero, and λ = decay constant. Since we usually know half-life τ rather than λ, we solve for λ in terms of τ by setting $n/n_0 = 0.5$ for $t = \tau$. The result is $\lambda = 0.693/\tau$. Thus $n/n_0 = e^{-\lambda t} = e^{-0.693t/\tau}$.

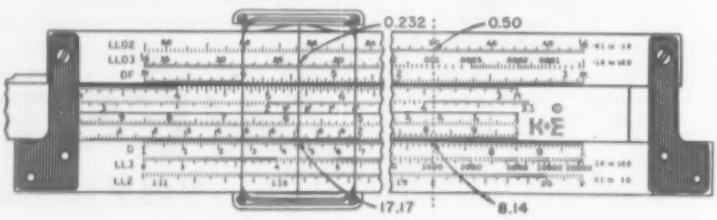
To solve any problem with a slide rule we must interpret it as sums and differences of logarithms. Here we can simplify matters as follows:

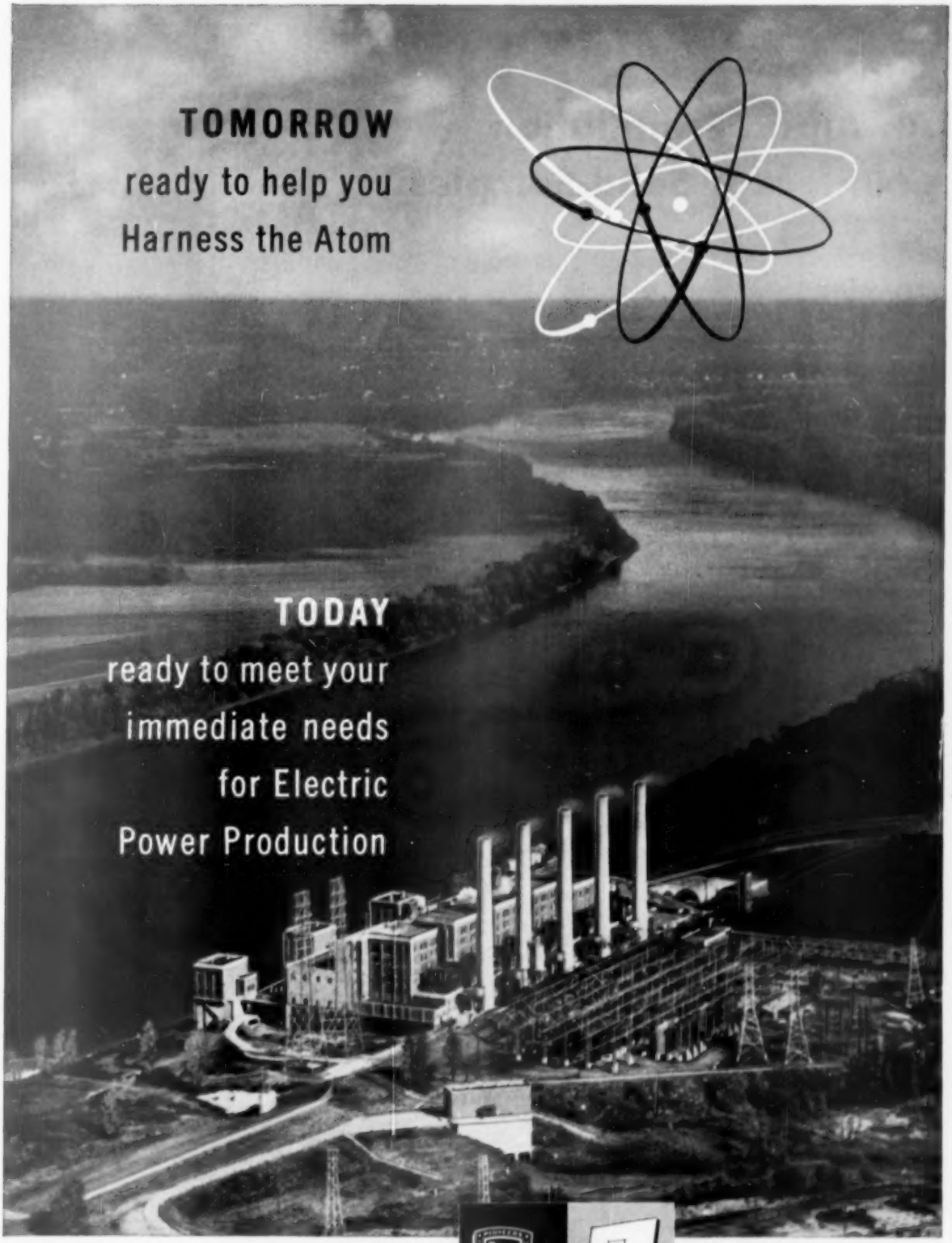
$$-\log n/n_0 = (0.693t/\tau) \log e$$
$$\log \log n_0/n = \log t + \log 0.693 - \log \tau + \log \log e$$
$$\log \log n_0/n = \log t + \log \text{const.}$$

One step of the work is done for us by the slide-rule manufacturer who marks the LLO scales with n/n_0 values instead of n_0/n. We select the proper value of "log const." by placing the half-life opposite 0.5. Since log log n_0/n is a linear function of log t, the slide rule becomes a decay table when it is properly set.

A slightly modified procedure may be required for a rule having only a log log scale for numbers greater than one. Here we can set the half-life opposite 2 and read the fraction n_0/n, the reciprocal of the number we used previously. Then we *divide* the original activity by this conversion factor to find the later activity.

The method is adaptable to any similar problem involving the exponential function with either positive or negative exponents. Shield thickness, for example, can be computed from the known half-value thickness.





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An Alpha Scintillation Counter for Solid Samples

By JOHN F. FRAZER

Radioactivity Center of the Department of Physics
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Du Pont type D ZnS(Ag) phosphor is mixed with a thin solution of rubber cement in xylene, deposited directly on the face of a Dumont 6292 photomultiplier tube, and allowed to dry. This provides a phosphor screen with a thickness of about 10 mg/cm² covering an area of 15.9 cm².

The solid sample to be measured is deposited on the surface of a Pyrex glass planchet, which is positioned about $\frac{1}{16}$ in. from the phosphor screen. The planchets are uniformly dimensioned for reproducible geometry from sample to sample. The sample-holding structure is shown in Fig. 1.

The photomultiplier is made light-tight by taping one end of a black rubber sleeve over the base of the tube such that the free end hangs down over the glass envelope. The free end is then folded back on itself and taped to the brass lip concentric to the tube base. A brass cap screws on the bottom of the brass tube, covering the source-holder structure and completing the light-tight housing.

Figure 2 shows the photomultiplier circuit. The cathode-follower pulse output is negative and is connected with a 1-msec *RC* time constant to the input of a Schmidt trigger discriminator calibrated from 0 to 100 volts and arranged to operate with negative pulses. Pulse heights measured at the cathode-follower output are as high as 100 volts for a 6-Mev alpha.

The discriminator is followed by a 4-stage dekatron scaler providing a scale of 10^4. Standard dekatron circuitry* is employed. A 300-volt regulated supply provides d-c power to the cathode follower, discriminator, and scaler circuits.

The photomultiplier with its batteries, the battery rotary switch, and the cathode follower are mounted on one 10 × 12 × 3-in. chassis, which is supported on an aluminum-rod frame so that the photomultiplier tube, in its brass enclosure, hangs photocathode down. A second chassis carrying all other components is placed on top of the photomultiplier chassis.

Operator controls are reduced to the minimum of an on-off power switch, a high-voltage (photomultiplier battery) on-off switch, a calibrated (0–100 volts) discriminator dial, a stop-count scaler switch, and a scaler reset switch. Screwdriver adjustments are provided for the regulated power supply and for zero set of the discriminator. A panel jack is available for oscilloscope monitoring of discriminator input pulses.

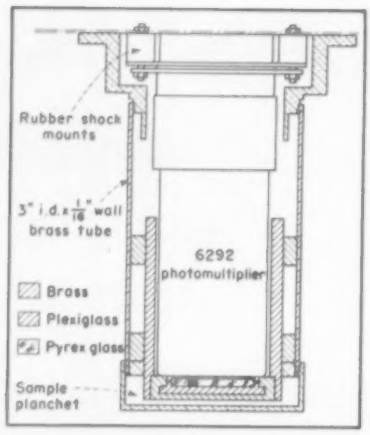

FIG. 1. Photomultiplier and sample holder are supported in brass tubular enclosure. Rubber shock mounts permit tube face to fit flat against Plexiglas structure. Except for slide-out sample holder, all Plexiglas is cemented into one piece free to slide within brass tube

A reproducible background count of about 4 counts per hour was measured with blank Pyrex planchets.

Photomultiplier battery life is about 6 months under continuous service conditions and proportionately longer with less use.

* * *

This work was supported in part by contract AT(30-1)-952 with the U. S. Atomic Energy Commission.

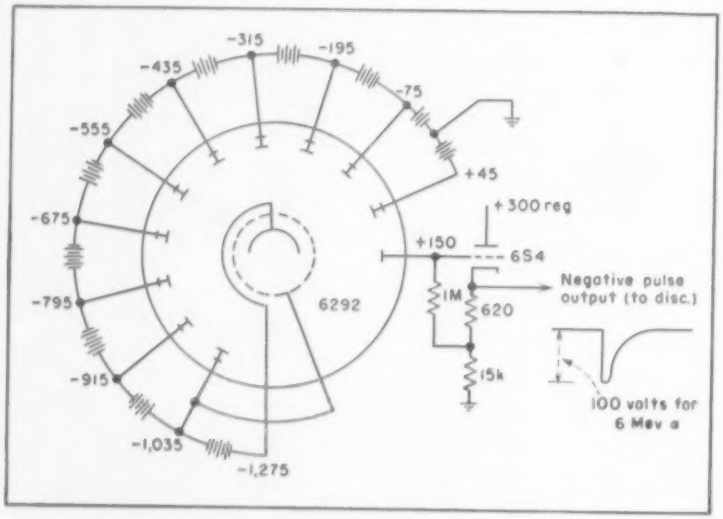

FIG. 2. In photomultiplier circuit, hearing-aid-size batteries between adjacent dynodes provide 120 volts per stage and 240 volts between cathode and first dynode. Rotary switch (JBT MS-20-2-6DT 12PDT) disconnects all batteries simultaneously to disable photomultiplier during sample changing. Anode is direct-coupled to grid of a-c-type cathode follower that places grid and anode at 150 volts positive with respect to ground. Dynode battery system is grounded at 45 volts below last dynode, thus fixing anode to last dynode voltage at 105 volts

* Dekatron-drive-circuit data sheets from Atomic Instrument Co., Cambridge, Mass.

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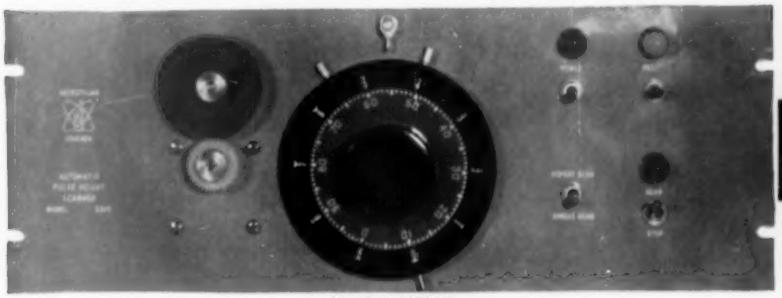

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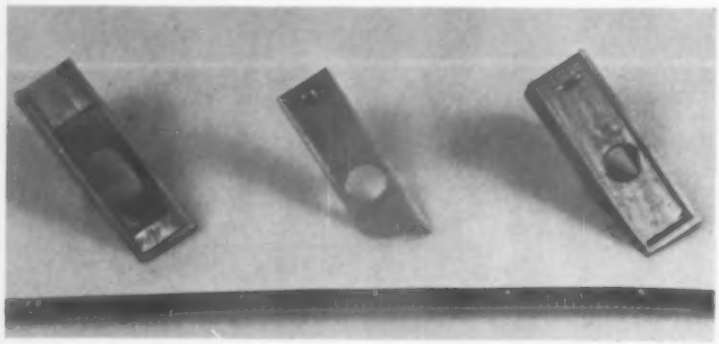

FIG. 1. Slide holder

Glass Slides Help Map Gamma Fields

By R. G. BAUMAN
Nuclear Developments Group
B. F. Goodrich Research Center
Brecksville, Ohio

Standard glass microscope slides may be used effectively in mapping high-level gamma-flux distribution.

Many different methods of gamma-flux measurement have been used in the past. These include instruments such as ionization gages or scintillation counters, chemical dosimeters such as the ferrous-ferric sulfate dosimeter, and photoconductive semiconductors. Several investigators (*1, 2*) have employed silver-activated phosphate glass in dosimetry work of this variety. These activated glasses are marked by their greater darkening at a given gamma dosage and by their relatively slow fading after exposure. However, we have found that ordinary microscope slide glass is satisfactory for gamma-flux field plotting if its optical density is measured within 10 hr of its removal from the field. Also the flux of gamma radiation used to calibrate the glass should be of the same order of magnitude as that to be measured,

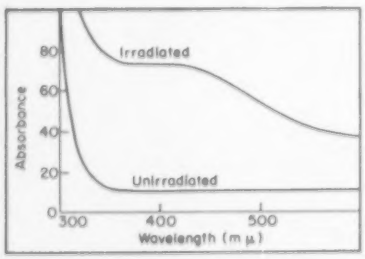

FIG. 2. Absorbance curves for irradiated and unirradiated microscope slide glass

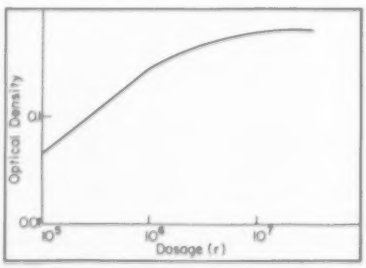

FIG. 3. Variation of optical density of microscope slide glass with gamma dosage

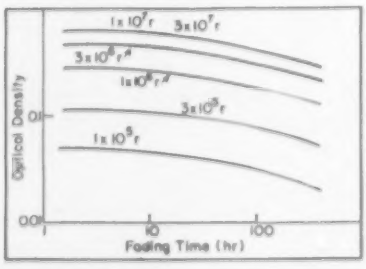

FIG. 4. Fading of irradiated microscope slide glass

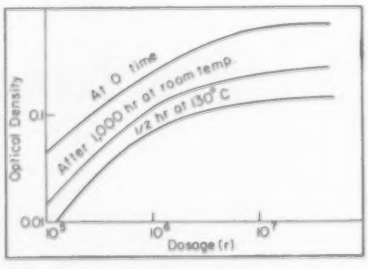

FIG. 5. Heat treatment of an irradiated microscope slide glass

if the glass is to be used as an absolute rather than relative measuring device.

Microscope slides (Pittsburgh, Non-Corrosive No. 12-550)* were cut to fit the holder shown in Fig. 1. The slides were wrapped in aluminum foil to prevent light from striking them and exposed in a Co^{60} gamma source to doses ranging from 10^5 to 3×10^7 r. Optical densities were measured against an unexposed blank in a Model DU Beckmann spectrophotometer at a slit width of 0.1 mm. The absorbance curves are shown in Fig. 2 for the unirradiated and irradiated glass. A wavelength of 520 mμ was chosen for the calibration.

The variation of optical density with dosage is shown in Fig. 3. The relationship is linear to 10^6 r. At higher doses it is obvious that the glass rapidly saturates. However, the range of 10^5–10^6 is a most useful one for gamma-flux calibration.

The fading of the glasses is shown in Fig. 4. The density decreases less than 10% in 10 hr. The effect of heating ½ hr at 130° C is shown in Fig. 5 where it is compared to 1,000 hr at room temperature. Heating for one week at 100° C resulted in almost complete removal of all color.

We have concluded that ordinary microscope slide glass can be used to determine gamma-flux fields with acceptable accuracy. This technique has been used in the calibration of the B. F. Goodrich Gamma Facility (*3*).

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2. H. Rabin, W. E. Price, NUCLEONICS **13**, No. 3, 33 (1955)
3. R. Bauman, to be published

* Glass composition is 72.08% SiO_2, 0.044 Fe_2O_3, 1.75 Al_2O_3, 7.34 CaO, 3.80 MgO, 14.36 Na_2O, 0.34 K_2O, and 0.25 SO_3.

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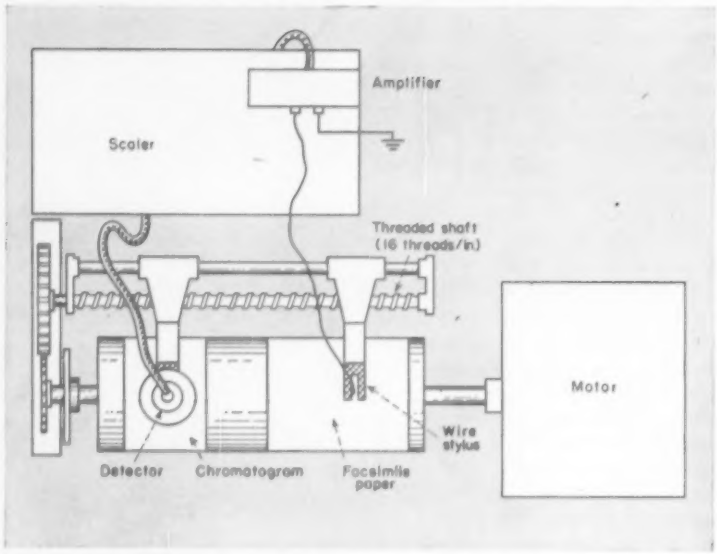


FIG. 1. Plan of scanner. Chromatogram is wrapped about metal drum and attached by tape; facsimile is wrapped around with overlap in direction opposite to drum rotation and cemented with rubber. Motor is multiple speed. Detector and stylus ride on smooth shaft and are driven by threaded shaft. Drum-to-threaded-shaft gear ratio is commonly 1:3. Bearing split at A permits changing drum size. Standard 20-in. kymograph drum perimeter is satisfactory for large chromatograms; 9-in. perimeter is superior for smaller quarter-sheet chromatograms since slower perimeter speed provides greater sensitivity. Same perimeter speed increases scanning rate

A Two-Dimensional Scanner for Radio-Chromatograms

By S. ARONOFF

Institute for Atomic Research and Department of Botany and Plant Pathology Iowa State College Ames, Iowa

Several devices are available commercially for rapid assay of chromatographic radioactivity. Almost without exception these are of the "one-dimensional" type, i.e., for narrow strips. With apparatus of this type the location of spots on a two-dimensional chromatogram requires sectioning, the certainty of location of the spot being a function of the width of the section cut. This is obviously undesirable if accurate location of the spot is needed, or if elution is required. The instrument to be described is a relatively simple two-

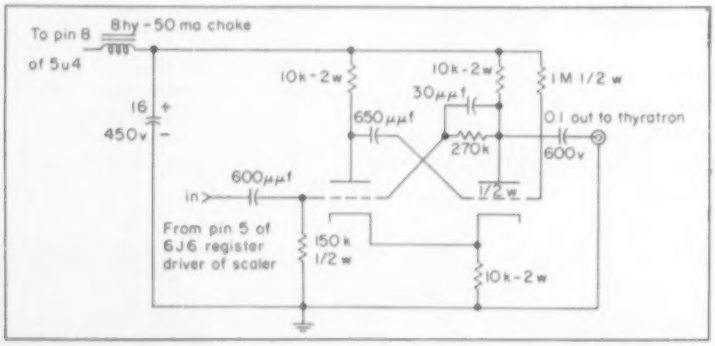


FIG. 2. Univibrator circuit modifying scaler to pass register impulse to thyratron. Filter prevents back emf's into scaler. Detailed central part of circuit is 6SN7 tube

dimensional scanner that prints two-dimensional facsimiles of radioactive chromatograms in a fraction of the time required for autoradiography.*

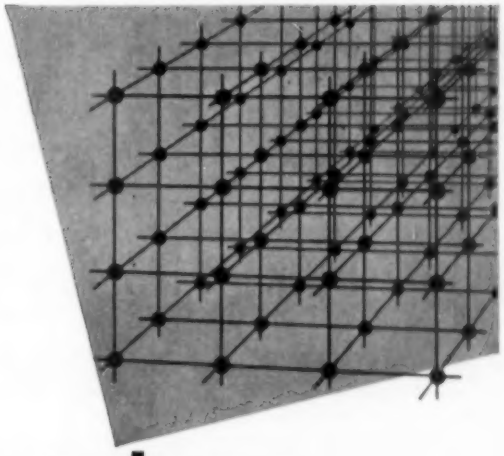
A diagrammatic plan view of the scanner is shown in Fig. 1. Any type of detector can be used. For convenience we have commonly used end-window G-M counters, occasionally converted to the flowing type using ultra-thin windows. The distance of the tube window from the drum is controlled by an adjusting screw. The stylus consists of 40-mil tungsten wire, although phosphor bronze wire is quite suitable if provisions are made for its renewal as it wears down; the wear with hard-drawn tungsten is negligible. The weight of the lever arm provides the pressure required for proper recording by the stylus.

The impulse from the G-M tube is fed into the scaler as usual. However, the scaler is modified to feed the register pulses to a thyratron tube whose action controls the output to the stylus. With each register pulse from the scaler, a mark is made on the facsimile paper.† With a scale selector any scaling factor may be used; our experience, however, has shown the scale of 2 to be most useful. (For most purposes the rest of the scaler is unnecessary and could well be dispensed with in future models.) The scaler modification (Fig. 2) consists essentially of a univibrator circuit, which delivers a square-wave pulse to the thyratron driver. Figure 3 is a diagram of the thyratron circuit and the power supply for the stylus. A variable voltage output (~150–250 volts) is provided for intensity control of the stylus mark.

The results of a test pattern chromatogram are shown in Fig. 4. It is apparent that only a point detector in direct contact with the spots would yield an accurate facsimile. The larger the sensitive area of the detector, and the further its distance from the source of radiation, the greater will be the distortion. Figure 4 shows that a practi-

* A two-dimensional scanner of greater complexity and designed primarily for scanning radioactivity incorporated within humans has been devised by Cassen and co-workers [L. Curtis, R. Cassen, NUCLEONICS **10**, No. 9, 58 (1952)].

† We have found Teledeltos, the Western Union facsimile paper, to be very satisfactory, as well as economical. This paper consists of an opaque black conducting base coated with a gray pigment. The latter is changed to a black color on passage of electricity. We wish to acknowledge a generous supply of Teledeltos paper by the Western Union Telegraph Co. (courtesy G. Hotchkiss).



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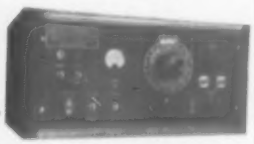

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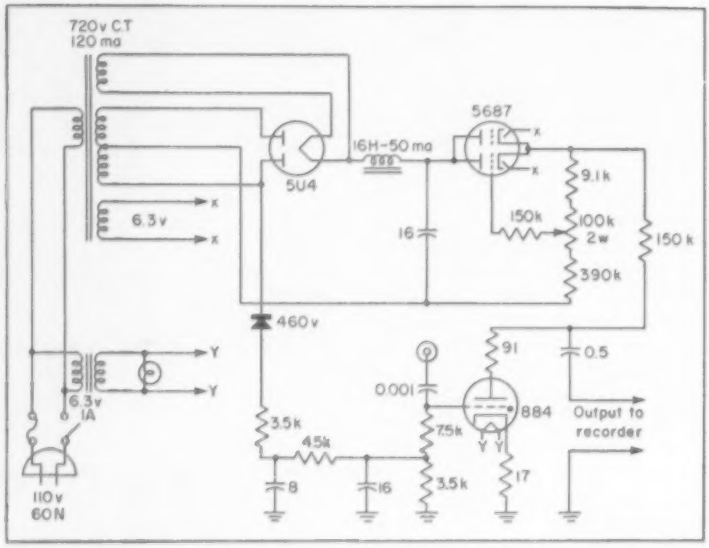

FIG. 3. Power supply and thyratron circuit

cal sensitive area is 0.5 cm² when the detector is ≤1 mm from the chromatogram surface.

The limit of sensitivity of the method appears to be equivalent to the ability of the mind to discriminate a pattern in an array of otherwise random spots. In a field of equal area of white and black, this is of the order of 5–10%.* In terms of the instrument described, this would mean a theoretical limit of 1.5–3 cpm if the detector has a natural background of 30 cpm. In practice, however, the practical limit at present appears to be around 100 cpm. It is apparent that this is independent of the type of detector, except for the ratio of the efficiency of the detector to its background count. Reduction of the background by means of a totalizer (i.e., nonprinting until a certain count is established, equivalent to changing from a scale of 2 to 16) or a counting-rate meter (nonprinting until a specified counting rate is attained), etc., may be used to diminish the background almost to extinction. However, at the same time very weak spots will be lost and the same effect may be obtained in a shorter time by more rapid scanning.

* * *

Grateful acknowledgement is made to I. Coleman and R. Picht for constructing the apparatus and to Al Reed, Ray Prior and John Bowes for designing and constructing the electronic circuits. This article is based on contribution No. 443 of the Institute for Atomic Research.

* Personal communication from R. Owens, Iowa State College.

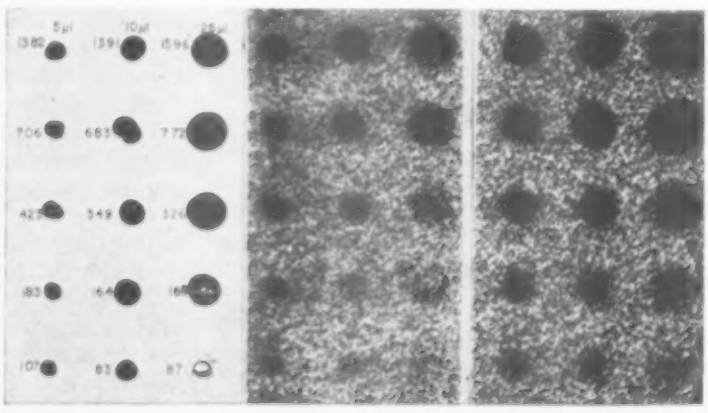

FIG. 4. Test patterns of chromatogram. At left is contact print of direct paper negative of autoradiogram; volumes at top are aliquots used; numbers to left of spots are counts/minute recorded by full window of G-M tube. At center and right are facsimile autoradiographs of the same chromatogram made using 0.5 and 1.0 cm² window openings, respectively

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Na cooled, D_2O moderated	40	10	10^4 kg U, ~2% enr.	D_2O	Liquid Na	950	Atm	850/850	5.5¶	1.85	7.35	735	1961
Wolverine Electric Cooperative, Hersey, Michigan													
Aqueous homogeneous	31*	10	12 kg U^{235}	U_2SO_4 in D_2O	Fuel sol'n.	570	2,000	585/486‡	2.486	1.088	3.574	357	1959
University of Florida, Gainesville, Florida													
Pressurized water	10	2	?kg, 30–40% enr.	H_2O	H_2O	450	1,200	200/407	1.4	0.2**	1.6	800	1959
City of Orlando, Florida													
Liq.-metal fuel, Th blanket	?	25–40	60 kg U^{235}, 17,000 lb Th	Graphite	U^{235} in molten Bi sol'n.	?	?	1,250/900	12.5	8	20.5	512–820	1960
Rural Cooperative Power Association, Elk River, Minnesota													
Boiling water	58	22	12 kg U^{235} spikes in 10,000 kg nat'l U	H_2O	H_2O	533	900	600/825	3.76	2.425	6.185	281	1960
City of Piqua, Ohio													
Organic moderated	45.5	44	6,300 kg, 3% enr.	Hydrocarbon	Hydrocarbon	617	30	410/550	3.34	1.96	5.3	424	1960
City of Holyoke, Massachusetts													
Gas cooled, closed cycle	44	15	70 kg, 5% enr.	Graphite	N_2 gas	1,292†	501	?	2.4	4.028	6.428	429	1960

* Includes 15.3-Mw superheater. † Maximum gas temp. at reactor outlet or turbine inlet. ‡ Gas-fired superheater boosts this to 550 psig, 825° F. § Not including research and development. ¶ Not including design cost. ** Not including building cost.

Reactors in AEC's Second-Round Power-Demonstration-Reactor Program

This table, showing the characteristics of the seven small reactor plants proposed in the second round of AEC's power demonstration reactor program, was prepared mostly by the Commission. Read together with NUCLEONICS' survey of the thinking of the seven proponents (NU, March '55, pp. 19–21), it gives a complete picture of the state of the small nuclear power plant art at this time.

Two of the seven have already been approved by the AEC—Wolverine Electric and Rural Cooperative Power Ass'n. The other five are still under serious study by an AEC evaluation board.

The first cost per installed kilowatt, shown in the next-to-last column, ranges from $281 to $800 or $820/kw. Comparable figures were computed by AEC for reactors in the first round of the power demonstration program, in the Commission's own five-year program, and in the independent privately-financed category. These figures afford a comprehensive survey of the cost of nuclear power today and of the distance that remains to be traveled to the goal of competitive nuclear electricity.

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These 17 reactors have a total potential electrical capacity of 914 Mw, although the five AEC experimental plants (excepting PWR) range only from 7.5 down to 2 Mw. Yet it is interesting to note how vast is the spread, caused by high developmental expenses, between their cost/kw figures ($450–960) and the relatively much more favorable figures on the New York and Chicago Edison plants, by far the largest projects.

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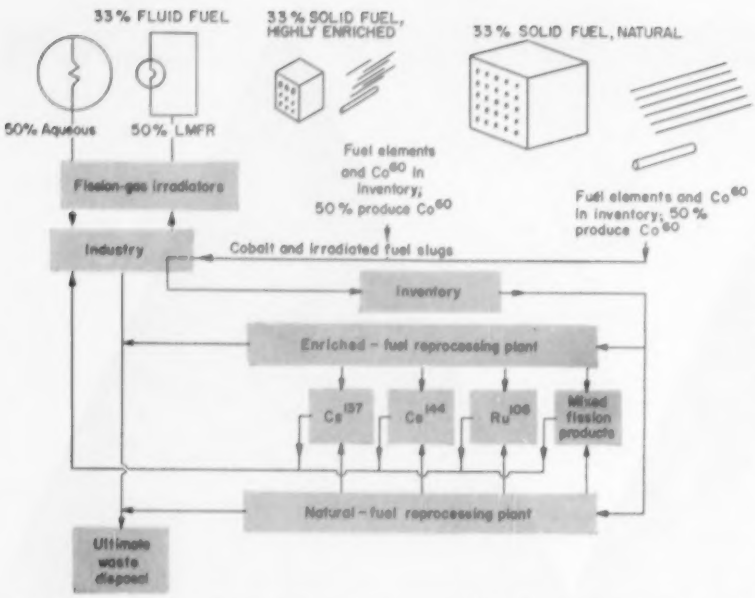

FIG. 1. Assumed development of nuclear economy. Of all reactors built, 33% will use fluid fuel (of which 50% will be aqueous and 50% liquid metal) and 67% will use solid fuels (of which 50% of fuel burned will be highly enriched and 50% natural U); 50% of solid-fuel reactors also will produce Co^{60}

Economic Future of Fission Products for Radiation Power

By B. MANOWITZ and D. M. RICHMAN
Brookhaven National Laboratory
Upton, N. Y.

In considering whether or not to enter the business of reprocessing spent reactor-fuel elements, one would like to take into account the possibilities of obtaining income from the process by-products—fission products. To evaluate properly the radiation power value of fission products requires a market analysis, a growth pattern, and an evaluation of competition. Information for such an evaluation is given here.

Competition

Both high-voltage machines and reactors can produce radiation sources. Comparison of the various techniques leads to an understanding of their potentials.

Machines. Some kind of high-voltage machine can produce the same kind of radiation one obtains from nuclear sources. This means that it will not be possible to set up monopolistic prices for nuclear radiation power, but rather that nuclear radiation power must always compete with high-voltage machines. Many such machines have been developed—Van de Graaff accelerators and X-ray generators among others—and the possibilities are that more, better, and cheaper high-voltage machines will be developed as the market grows. High-voltage machines have the advantages of constant power output and discontinuous operation—power is not dissipated except when the machine is in use. They are now manufactured to sell at prices of about $100,000/kw, but probably can be produced at $10,000/kw in large units.

Reactors. Reactors themselves represent an important source of radiation. Conceivably, if a reactor is designed appropriately, as much as 50% of its total power could be used for radiation purposes. There are two distinct classes of reactors to consider: the fluid-fuel and the solid-fuel types.

Fission-product gases. In reactors using liquid fuels, such as the LMFR or HRE, the radioactive gases produced during fission could be continuously extracted and used right at the reactor site. In this way, as much as 0.5% of the total power of a fluid-fuel reactor can be extracted as gamma-radiation power.

Spent fuel elements, Co^{60}. Solid-fuel reactors are sources of radiation in two different ways. First, spent fuel elements can be used as radiation sources while they are in inventory prior to going through the fuel-recovery process. Second, very significant amounts of Co^{60} can be made by irradiating cobalt metal in regions of the reactor where neutrons ordinarily would be lost from the system.

Mixed fission products, separated long-lived components. The fission products can be separated from the fuel at the fuel-recovery plant and either packaged as mixed fission products or separated further into the long-lived components and waste.

The isotopes having high-energy radiations and long half-lives are Ce^{144}, Ru^{106}, Cs^{137}, and Sr^{90}. However, Sr^{90} does not give off gammas, and Ce^{144} and Ru^{106} will be useful only for very special purposes (remote heat sources, beta sources); thus they will not be considered in this analysis.

Growth Pattern

To get some feeling for the potential supply of fission products and other sources of radiation, we must make some assumptions—first as to how our nuclear economy will develop, and second, as to how it will grow. Assumptions on nuclear economy development are in Fig. 1.

Development of nuclear economy. It has been assumed that of all reactors built, 33% will use fluid fuel and 67% will use solid fuels. Of the fluid fuels, 50% will be aqueous and 50% liquid metal. Of the solid-fuel units, 50% of the total fuel burned will be highly enriched and 50% natural uranium. It has also been assumed that 50% of the solid-fuel reactors also will produce Co^{60}.

For purposes of calculation, sizes and shapes for the fuel elements have been postulated. Half of the natural and half of the enriched slugs have been assumed to be 1 in. in diameter and at least 1 ft long; others might be 0.18 in. thick by 1 in. wide and at least 1 ft long. All slugs would have 30 mils of aluminum cladding. Further it has been assumed that all fuel has been irradiated for 100 days and cooled for 90 days

at the time of use for radiation power.

Growth of nuclear economy. Figure 2 shows the nuclear-economy prediction in terms of the nuclear-heat power that will be generated yearly from 1961 to 2000 (*1, 2*). Calculations made from these data are presented in Table 1 and Fig. 3. Table 1 is the accumulation of radiation power by the year 2000 from all sources considered, given both in terms of curies and in terms of gamma power; it takes into account self-absorption and Bremsstrahlung generation. The fission-product figure considers that only 75% of all the fission products produced by the projected nuclear-power economy have been recovered. It is conservative in that it does not take into account the fission products available from fuel burned by military reactors.

It is evident from Table 1 that a very large amount of radiation power will be accumulated. Note that although more curies of Cs^{137} than of Co^{60} will be accumulated, in terms of the available gammas less radiation power will be accumulated in Cs^{137} than in Co^{60}.

Figure 3 presents the yearly production rate of gamma power, it also shows how the geometric factors influence the gamma power available. While enriched-uranium cylinders and plates and natural-uranium cylinders and plates all have the same curie content, the enriched plates release more gamma power than the others; the natural-uranium cylinders release the least.

The gamma power accumulated from uranium slugs in the year 2000 will be the same as the production in that year, since the fuel slugs are destroyed in the separation plant at the end of one year of cooling.

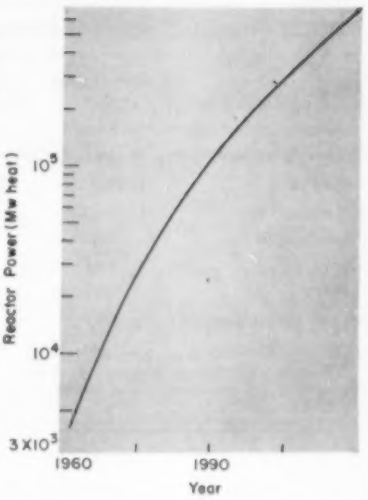

FIG. 2. Assumed growth of nuclear economy in terms of nuclear-heat power (*1, 2*)

Radiation-Power Cost

To permit evaluation of the competitive status of the radiation sources described, the supply and probable cost of these sources in 1965 and in 2000 are given in Table 2. The probable costs of these various sources of radiation power will be influenced by the costs of: (a) retaining the fuel at the reactor site, (b) making Co^{60} instead of converting fertile materials, and (c) recovering and packaging fission products.

Retaining fuel at site. The cost of retaining fuel elements at a reactor site will be influenced by the inventory charges on the unburned portion of the fuel element and by the cost of shipping the fuel element to the fuel-recovery plant. If all of these costs are to be recovered, the use cost for the fuel ele-

TABLE 1—Accumulation of Radiation Power by the Year 2000

Source	*Curies*	*Total Mw*	*Gamma Mw*	*Beta Mw*	*Transmission* %γ	%β	*Available* γ*Mw*
Co^{60}*	2.4×10^9	40	34.6	5.4	70.6	0	24.4
Ru^{106}*†	0.9×10^9	17.6‡	1.5‡	16.1	62.5	40	0.9
Ce^{144}*†	1.0×10^{10}	201.0§	11.0§	190.0	78.5	48	8.0
Cs^{137}*†	4.2×10^9	29.2	15.2	14.0	79.5	0	12.0
Nat'l. U, 1 in. diam.	4.0×10^{10}	175	84	91	21	0	17.6
Nat'l. U, 0.18 in. thick	4.0×10^{10}	175	84	91	44	0	37
Enr. U, 1 in. diam.	4.0×10^{10}	175	84	91	61	0	51.2
Enr. U, 0.18 in. thick	4.0×10^{10}	175	84	91	69.2	0	57.2

* 0.18-in. thick plates. †Accumulation here is for material as separated isotope. These isotopes are also present in the fuel slugs, and are included in the curies of fuel slugs in that case. ‡ 0.4 Mw are due to Bremsstrahlung. § 0.8 Mw are due to Bremsstrahlung.

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TABLE 2—Probable Supply of Radiation Power

Probable sources	*1965 supply (kw)*	*2000 supply* (kw)*	*Probable Cost† ($/kw)*
High-voltage machines	Unlimited	Unlimited	5,000–10,000
Reactors	Unlimited	Unlimited	~4,000
Fission-gas reactors	Unlimited	Unlimited	~20,000 (no credit for power)
Fuel elements	920	160,000	<13,000
Co^{60}	260	24,000	~8,000
Cs^{137}	66	12,000	
Mixed fission products	800	140,000	

* Supply indicated is accumulated supply for Co^{60} and Cs^{137} and is production rate for that year for fuel elements and mixed fission products.
† 50-kw units.

ment as a radiation source is likely to be ~$13,000/kw on a three-shift-use basis. Lower charges than this might be made, depending on what fraction of their inventory and shipping charges the reactor operators decide to recover.

Co^{60} vs. converting fuel. The cost of Co^{60} radiation can be estimated by assuming that fissionable material, such as U^{233}, could have been made in the same region of the reactor in which the cobalt was placed, and charging $25/gm for the fissionable material. On this basis Co^{60} will be worth about $8,000/kw.

Fission-product recovery. Costs for Cs^{137} and for mixed fission products are difficult to assess because they involve processes for recovery and packaging that have not yet been developed. But the cost for Cs^{137} is likely to be greater than $10,000/kw, while mixed fission products are likely to be in the $10,000/kw range.

Market Analysis

Table 3 roughly estimates the probable markets for radiation power based on uses now under consideration. The analysis assumes that irradiators of various sizes will be produced to service different markets.

Chemicals. The estimate has been made for the chemical industry by assuming that radiation will capture the total market for entirely new products or processes, and about 10% of the total market for products or processes for which competitive techniques exist. An analysis was made of the 1965 market and projected to 2,000 by assuming a doubling time of 7 years for the industries involved.

Foods. The food industry was considered to double in size from 1965 to 2000; 1–10% of the food industry is expected to use radiation by 1965.

Applications

The conclusions one may reach from Table 3 are:

1. Cs^{137}, high-voltage machines, and Co^{60} are now and will continue to be competitive for the radiography and therapy markets.

2. The sterilization of drugs and medical supplies is a relatively small market that, even in 2000, probably can be saturated by 500 kw of radiation power. High-voltage machines probably will capture a large fraction of

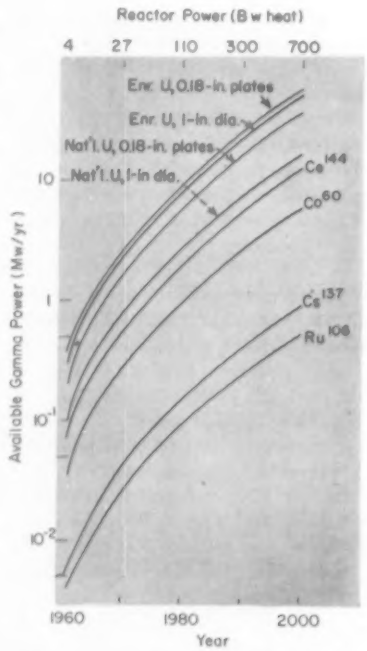

FIG. 3. Assumed annual production rate of gamma power. While enriched-uranium cylinders and plates and natural-uranium cylinders and plates all have the same curie content, the enriched plates release more gamma power than the others; natural-uranium cylinders release the least

TABLE 3—Probable Market for Radiation Power

Size of irradiator (kw)	*Probable selling price ($/kw)*	*1965 total market (kw)*	*2000 total market (kw)*	*1965 (no. of units)*	*2000 (no. of units)*	*1965 total ($)*	*2000 total ($)*
Radiography, therapy							
0.25	100,000	50	250	200	1,000	5×10^6	25×10^6
Drugs, medical supplies							
1	50,000	100	500	100	500	5×10^6	25×10^6
Specialty chemicals, specialty plastics, specialty foods							
5	30,000	1,000	5,000	200	1,000	30×10^6	150×10^6
Trichinae in pork; insects in wheat, corn, and coffee; potatoes; polymerization; vulcanization; polyesters; poultry; fresh vegetables; fresh fruits; canned foods; red meat							
50	10,000	30,000	100,000	600	2,000	300×10^6	1×10^9

this market, since they can be developed faster. Co^{60} and Cs^{137} may be competitive.

3. High-voltage machines and Co^{60} probably will be competitive for the specialty chemicals and foods market, and probably will capture a large fraction of the market. Cs^{137} may bid for a small fraction of the market. Fuel elements and mixed fission products may find some use here, particularly if the specialty items can be brought to the source. This is a market that will be generally available for small business.

4. There will be a large market and an opportunity for many good-sized industries in the various high-throughput uses for radiation power. The market will be sufficiently large to allow for competition between high-voltage machines, reactors, fuel elements, and mixed fission products.

Effect on economy. There will be a direct impact on the national economy in that a new industry will be born, but the indirect effect on the economy will be much greater still. Radiation sterilization of food may change market practices and packaging techniques. Radiation techniques for making standard chemicals will alter process-equipment manufacture. New and unique products could alter major industries of today.

Effect on nuclear-power industry. The effect of the radiation-power business on the nuclear-power business itself is likely to be small. The operators of nuclear reactors may recover some fraction of the cost of inventory and shipping of fuel elements, and may get a small income by selling Co^{60}.

Fuel-recovery operation. From the point of view of the operator of a fuel-recovery plant, it should be noted that in 1965 Cs^{137} probably will be applied to the $30,000/kw to $100,000/kw markets; while by 2000, the supply will be great enough so that some Cs^{137} may have to enter the $10,000/kw market.

Because of their short half-lives and abundant supply, mixed fission products probably should be considered as applicable only to the $10,000/kw market.

Which Type Plant?

One of the choices facing the designer of a fuel- and fission-product-recovery plant is whether to install a facility for recovering Cs^{137}, a facility for recovering mixed fission products, or both.

Cs^{137}. Assume that a fuel-recovery plant is to be built that will process either 100 kg/day of enriched U (25% burnup), or 5 tons/day of natural U (4,000 Mwd/ton). It would produce 50 kw/yr of Cs^{137}, and about 5,000 kw/yr of mixed fission products. If, on the average, Cs^{137} sold at $50,000/kw, the income to this plant would be $\sim \$2.5 \times 10^6$/yr.

Mixed fission products. Although Cs^{137} can be sold on a kw basis (since its half-life is so long—37 yr—it can be considered part of a piece of capital equipment), mixed fission products, because of their short useful life, cannot. It would be more reasonable to assess the value of mixed fission products on the basis of energy delivered.

If mixed fission products were used in the period 100–300 days cooling, the initial radiation power would decay by a factor of two. Suppose, then, that we supply twice as much fission products as will be needed at the normal operating level of the device, but charge only for the normal operating level.

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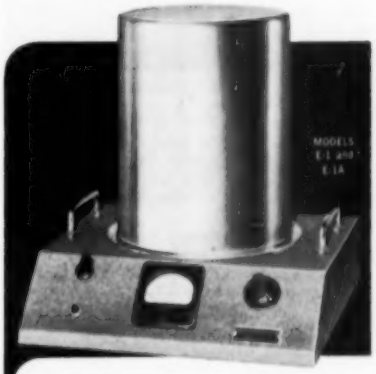

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Justifiable investment. A competitive high-voltage machine at $10,000/kw, amortized over 5 yr and used for a 2,000 hr/yr, would cost $1/kwh. At this rate a 50-kw mixed-fission-products device (containing 100 kw of MFP) operating for 1,100 hr/200 days would be worth $55,000. Our proposed plant could turn out 50 such devices per year, so that the income from this source would be $2.75-million. Typical chemical plant experience for plants of this size indicates that 20% return on capital investment after corporate income taxes can be obtained where the total capital investment is about 66% of the annual sales. On this basis, an investment of about $1.8-million is justified for either the Cs or the mixed-fission-products recovery plant.

Waste disposal. Finally, the economics must be considered in the light of the waste-disposal cost. For a processing plant of the capacity described, waste disposal is likely to cost ~$1.5-million/yr—5 ton/day × 1,000 gal waste/ton × $1/gal. Some of this should be credited to the fission-product recovery plant, since the waste inventory will be decreased.

On these bases, it appears that the recovery of fission products can be a profitable venture—one that should be considered seriously by anyone desiring to enter the fuel-recovery business.

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2. Palmer Putnam, "Energy in the Future" (D. Van Nostrand Co., Inc., New York, 1953)

REACTOR FACTS

Cut gamma-shield shipping costs with U^{238}. To shield a gamma-emitting material with a shield that's thick compared with its central cavity, a depleted-uranium shield would weigh less than a lead shield. The higher the specific gravity of shielding material, the less total weight is required—since shield effectiveness depends on thickness, while shield weight varies nearly with the cube of thickness. If made of 11.3 gm/cm³ lead, a spherical shield with a 2-in.-dia. cavity for the high-energy gamma source might be 4 in. thick and weigh 210 lb. But, with the same cavity and source, a shield of 18.7 gm/cm³ U would be 2.42 in. thick and weigh only 110 lb.

Transportation savings mount up when shipping large quantities of such radioisotopes as Na^{24}, whose short half-life (14.8 hr) makes it necessary to ship by air.

Ground operation for nuclear aircraft to be complex and costly. Spare runways for use in case of contamination, shielded engine run-up stations, remote "hot" shops for maintenance and fuel handling, disposal of contaminated materials, shielded vehicles, and other special equipment are expected to make nuclear-aircraft ground operations relatively expensive.

Con Ed critical assembly to operate this fall. Babcock & Wilcox this fall will initiate a 1-yr series of experiments on a critical assembly simulating the core of the reactor to be built for Consolidated Edison of New York.

The 6-ft-high × 6-ft-dia. test unit being built at B & W's new Lynchburg, Va., facility (see p. 21B) is said to contain the largest amount of U^{235} (200–300 kg) in any critical experiment and to be the first to use thorium (8,600 kg Th^{232}).

The experiments will give data on control-rod effectiveness, how much U^{235} is needed for criticality, the power distribution, and the conversion ratio. The ratio of U^{235} atoms burned up to the number of U^{233} atoms formed is expected to be about 0.7 initially; average conversion ratio will be less because of buildup of fission products. (PWR conversion ratio is predicted as 0.8). The Con Ed reactor core life is expected to be about one year (not including fuel-element shifting); at which time there will be 65–70 kg of U^{233} in the core.

Each of the 110–112 fuel assemblies will be 6 ft high by 6 in. square and will have 98 plates. The plates containing U^{235} are 60 mils thick; they are separated from adjacent 80-mil-thick Th-containing plates by a 100-mil thick water channel.

The nineteen control rods will be independently actuated by hydraulic drives mounted below the core vessel. The absorber sections will be above the core (for gravity drop). Of boron steel, the rods will be arranged in two concentric rings with one regulating rod in the center. The temperature coefficient is $-1.5 \times 10^{-4} \Delta k/°F$—too small to do without rods.

The core pressure vessel will be 23 ft high, 10 ft in diameter, and 6 in. thick; it will be made of carbon steel clad with stainless steel 304 or 307.

Zinn Letter

Continued from p. 35

is used in other reactors where the fuel element core is of small dimensions.

Increasing the temperature of the uranium rapidly involved very considerable chance of distorting the fuel-element jackets, especially since uranium metal and stainless steel form a eutectic at about 725° C. This is very little above the temperature to which it was desired to pulse the fuel elements.

3. That there was some risk of melting the fuel elements was well appreciated. In fact, when the experiments began in November, 1955, I, as a matter of course, informed the Atomic Energy Commission that in my opinion there was a real possibility that such results could follow. I also expressed the opinion that the information being sought was highly necessary and that the risk to be taken was not excessive.

4. The experiment to be successful required sizable temperature excursions with short time constants. A comparison would be the Borax experiments on water-moderated reactors that were done by Argonne in 1953. The excursion in question was one in which the power doubled about every 0.27 sec. The temperature of the uranium was to be permitted to rise to approximately 500° C. This meant that the shutdown of the reactor would have to be rapid and would have to be initated at the proper instant. Because of the rapid temperature rise required by the experiment, an error of one second in initiating the shutdown could be expected to give trouble.

From some news reports the impression may have been gained that no instrumentation was used. This is erroneous; the normal multiple-circuit power-level shutdown instrumentation was fully operative, and, in fact, acted swiftly and correctly when the normal operating power was reached. The reactor-period meter was disconnected since it did not have the flexibility that would permit it to be used for excursion experiments. It might be noted in passing that in other cases where like experiments have been done, it has been found impossible to make use of period meters.

5. In previous experiments of this type, it had been possible to interrupt the excursion and return the reactor to low power by making use of the motor-driven control rods. These subtract reactivity slowly. In this excursion, the technician at the control panel was expected to use the fast-acting shut-off rods upon receipt of a spoken instruction from the scientist in charge, who was observing closely special neutron and temperature recorders. These instruments were special in the sense that they had time constants much shorter than the normal operation instruments. Upon receiving the instruction to shut down the reactor, the technician repeated the use of the slower control rods. The staff scientist, as soon as he realized the situation, reached over and pressed the rapid shut-off button and, simultaneously, the automatic power-level trips responded to activate the shut-off rods. The delay in time, which was at most two seconds, was sufficient to permit the reactor power to overshoot to a point where the alloying of uranium and steel and melting of the uranium took place.

6. The reactor, of course, shut down and there was no way by sound or sight to know that anything untoward occurred. The record of the power level of the reactor as indicated by the neutron flux did show that the power surge might have raised the temperature of the fuel elements too high, but the many thermocouples attached to the fuel did not show an excessive temperature. Past experience has been ample to show that where thermocouples are imbedded in uranium metal, rapid changes in temperature may not be recorded. This is a classical difficulty in instrumentation for this type of work and the fact that the fuel melted shows that the thermocouples, indeed, did not follow the actual temperature rise. This detail is related to indicate one of the reasons why this type of experiment is extraordinarily difficult.

7. How, then, was it known that melting of the fuel had occurred? There was, of course, no unusual noise, explosion, or fire. It is characteristic of this work that the first indication came through radioactivity. After a period of 15 minutes, detectors for radioactivity installed both in the cooling system, some distance from the reactor, and in the ventilation exhaust ducts of the building began to show readings higher than normal. For the detector installed in the cooling system, it could be inferred that gaseous radioactive fission products had diffused through the gas blanket connections to the point where the detector was installed. (It should be recalled that the coolant was not flowing.) The activity in the building exhaust, while low, also was abnormal. This was due to the fact that the thermocouples for this experiment had been installed with temporary connections that did not seal gastight, so that some of the radioactive gas in the reactor vessel diffused into the room. As a precaution, the room was evacuated promptly. Normal use of the room was resumed just as soon as quantitative measurements of the activity could be made. On later examination, it was found that while some of the fuel rods could be removed, many could not be pulled through the holding plate.

8. Fuel from this reactor is sent for processing to the Reactor Testing Station chemical processing plant. An extended period of radioactive decay is desirable before chemical processing begins. Since the procedure of lifting the core holder and the fuel elements as a unit from the reactor is easier if the radioactivity has decayed, this operation has been delayed while the cooling takes place. Inasmuch as there is no program immediately requiring the use of the reactor, there is no urgency about removing the core. In due course, this will be done. Once the damaged fuel elements have been cut away, it is expected that the core holder can be reassembled and dropped back into the reactor tank. This last statement is speculation and must remain so until the actual inspection takes place.

9. There has been considerable comment concerning the fact that the events of November 29 were not reported publicly. Since it is believed that experiments of this type and the mishaps that can be expected when such experiments are attempted should not be classed as accidents, this event was handled and reported as any other experiment. I would like to make a very strong plea that this is the only reasonable and sensible thing to do. One cannot expect technologists to undertake difficult tasks if a public debate is to be anticipated whenever everything does not proceed altogether according to plan.

Events similar to the EBR-I case have taken place a number of times in the past and will again in the future. It would be a disservice to the progress of our atomic energy program if such occasions are not treated as unfortunate penalties exacted by the necessity of getting on with the job.

10. There also has been some comment that information vital to industrial programs was withheld. This is not true, since the only company that conceivably could have a prime interest

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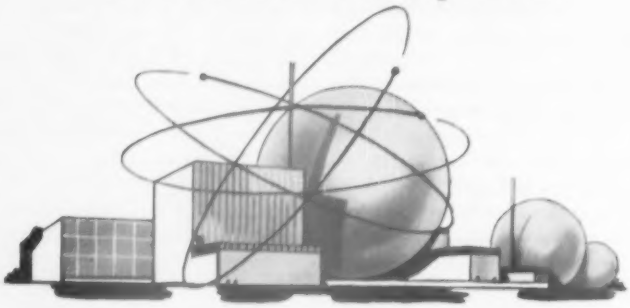

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in the experiment being performed, namely the Atomic Power Development Associates, Inc., had a representative present as a participant in the experiments.

11. It also has been claimed that the AEC was not informed. On the contrary, the AEC was informed by me on November 30 by telephone and, subsequently, in a number of written statements. At other times, AEC officials have received firsthand accounts at the site from the scientists who were performing the experiment. Also, the Atomic Energy Commission's Advisory Committee on Reactor Safeguards was informed to insure that no misinterpretation of the matter could affect the deliberations of that committee. It must be pointed out that no one was injured, and that the mechanical damage, it is expected, will be confined to the fuel elements, which were to be dissolved anyway. There is justification, therefore, in the belief that information was not withheld from anyone who could profit by it.

12. The unplanned part of this experiment has yielded some information of a useful nature as follows:

a. The behavior of the reactor was observed as its power rose into the damaging region, and it was evident that no unforeseen or catastrophic processes occurred.

b. The melting behavior of fuel elements in liquid sodium was observed for the first time under actual conditions of reactor operation. The metallurgical behavior of fuel elements and their containers under conditions of rapid melting or softening is one that can be studied in no other way than by the rapid increase of power in an actual reactor. Examination of the fuel elements should yield important data on this behavior.

c. The relative ease with which the radioactivity released into the reactor coolant was controlled has indicated that the melting of highly radioactive fuel elements in sodium is not very hazardous to the reactor surroundings. Observations on the behavior of this activity may be of value in the development of methods of detecting individual fuel-element failures in power reactors.

d. The process of removing the core will provide new experience since it is the first highly radioactive sizable object to be removed from a sodium coolant. If this experience is favorable, it may lead to economies and simplifications of handling methods in

Continued on p. 119

TECHNICAL ADVANCES

Gamma-Sensitive Xe Bubble Chamber Liquid xenon is being used in a bubble chamber (liquid analog of cloud chamber) to give a gamma-sensitive medium that can give accurate information about the tracks of charged secondaries. The new technique is very promising for high-energy experiments and may have application at low energies, particularly in light of the relation to liquid-xenon scintillation counters discussed at the recent scintillation counter symposium (NU, May '56, p. 36).

D. A. Glaser and associates at the University of Michigan have just completed the first liquid-xenon bubble chamber. Sensitive volume is 1 in. in diameter and 1½ in. deep, but there is no basic size limitation. Tracks of Compton secondaries from radium gamma rays are clearly visible in photographs taken with a 5-μsec flash 3 msec after expansion. Ease of track scanning and low background are additional advantages.

An interesting sidelight concerns the failure of the chamber to operate when first tried with pure xenon. This was presumably due to the high scintillation efficiency of liquid xenon, which caused much of the energy of the particle to escape as light rather than contribute to the local ionization and heating necessary for bubble formation. Addition of 2% (by weight) of ethylene quenched the scintillations sufficiently to permit the bubble chamber to bubble. Glaser wonders if one couldn't adjust the amount of quenching material to give simultaneous scintillation and bubble-chamber properties. This then could permit time measurements on particles whose tracks could be made visible milliseconds later.

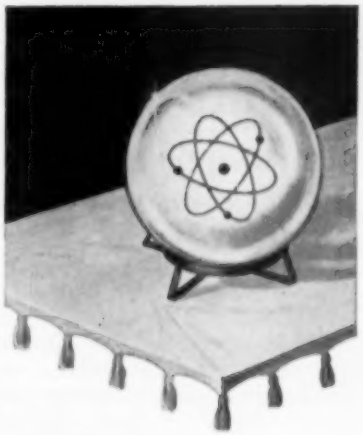
Californium-252—New Neutron Source? Spontaneous fission in the transuranic elements can provide a new source of neutrons very much more intense than radium-beryllium sources currently employed. Thirty milligrams of californium-252 will provide 10^{11} neutrons/sec—10 kg of radium would be required to provide a source of this intensity.

Key to production of Cf^{252} is long-term irradiation of plutonium in high reactor fluxes to provide the chain of captures required. Calculations at Argonne National Laboratory show that for a flux of 3×10^{14} n/cm²/sec with constant replenishment of the Pu, production of Cf^{252} will be 0.7 μg/gm of Pu consumed after 4.5 years, 0.1 mg/gm after 10 years, 1 mg/gm after 20 years; for infinite irradiation production is 6 mg/gm. (Since Cf^{252} has a relatively short [2.2 yr] half-life it would be milked periodically.) For a 20-Mw thermal Pu reactor a 10^{11}-n/sec source would be produced every 25 days after ten years, every 2.5 days after twenty years.

Plutonium-fueled reactors or special long-term irradiations in high-flux test reactors could provide such sources—but it will take time. (Detailed article forthcoming in NUCLEONICS.)

Gamma-Ray Monitors For Reactor Startup Experiments performed at Oak Ridge point the way to possible use of gamma-ray monitors for reactor startup instead of the neutron monitors conventionally used. Gamma-ray monitors offer the advantage of being relatively unaffected by the movement of components of the lattice or reflectors around it. In addition the gamma-ray monitor could be located farther from the center of the reactor without sacrificing response time.

The problem is to get a detector sensitive primarily to prompt-fission and neutron-capture gamma-rays rather than fission-product gamma rays, for only the former are proportional to power level. R. J. Kerr and C. J. Borkowski of the controls division at ORNL looked into the response of NaI, plastic scintillators, and Cerenkov counters with the swimming-pool reactor operating and off and with "hot" and "cold" fuel elements. They find NaI best using a 3 × 3-in. NaI crystal 2 m from the reactor face and with discriminator biased to cut out gamma rays below 2.76 Mev, the reactor operating at 7 w gives 70× the counting rate when shutdown. Counting rates are comparable with those from a fission chamber placed 6 in. above the lattice. Since the problem is primarily one of getting increased relative response to high-energy gamma rays, a useful approach might be to use a Cerenkov counter of low index of refraction (~1.01) to discriminate absolutely against electrons below ~3 Mev.



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BOOKS

The Metallurgy of Zirconium

Edited by B. LUSTMAN and F. K. KERZE, Jr. (McGraw-Hill Book Co., Inc., New York, 1955, xviii + 776 pages, $10.00).

Reviewed by STANLEY KASS, Westinghouse Electric Corp., Atomic Power Div., Pittsburgh, Pa.

With the advent of nuclear energy for power uses, research and development programs were initiated to determine the properties of zirconium. The results of the programs are very well presented in the latest volume of the McGraw-Hill National Nuclear Energy Series, and has begun to close the gaping hole in our knowledge of zirconium.

The aim of the book is to introduce the reader to zirconium. It leads him step by step from the applications of zirconium through processing and fabrication, to the physical, corrosion, and mechanical properties. To further this end, the book is copiously illustrated and includes many data tables. The authors have produced a combined handbook-textbook that should prove invaluable to all concerned with zirconium.

Perhaps the range of topics treated in the volume is indicated best by a brief summary of the chapters.

The first three chapters of the book point out the reactor and nonreactor applications of zirconium as well as the occurrence, reserves, and mining methods for zirconium-bearing ores.

The methods for the production of zirconium are discussed in chapter 4. A complete technical and historical picture of the Kroll process is included along with a discussion on the thermodynamic properties, which effectively introduces the reader to the electrochemical processes involved in the recovery of zirconium from its ores.

The product from the reduction process usually contains small amounts of impurities, which, if found to be deleterious in the end use, can be removed by the iodide-decomposition process fully described in chapter 5.

Chapters 6 and 7 discuss the melting, shaping, joining, and finishing of zirconium and its alloys. Included is an excellent discussion, complete with equipment sketches and operational notes, on consumable and nonconsumable electrode arc-melting in vacuum and inert atmospheres, as well as induction, resistance, and drip melting.

For the research worker, chapters 8 and 9, *Physical Metallurgy of Zirconium and Its Alloys* and *Phase Diagrams of Zirconium Alloy Systems*, should prove very helpful.

The mechanical properties and the effects of many variables, i.e., melting practice, temperature, grain size, hot and cold work, heat treatment, etc., on the tensile, creep, impact, and fatigue properties are ably summarized in chapter 10.

The excellent corrosion properties that have more or less dictated its use in power reactors are discussed in chapter 11, which is divided into five sections: gas-metal reactions; corrosion in water and steam; corrosion in acids, bases, and salts; corrosion in liquid metals; electrode reactions.

Chapter 12 and appendices A and B include the analytical chemistry and the metallography of zirconium, necessary information for all working with zirconium.

The authors have attempted successfully to combine in each chapter both specialized and generalized features of the topics, thereby making the book useful to the experienced worker and to the newcomer who desires a general survey.

There is one basic difficulty involved in a book concerned with as wide a scope as the programs involved in research and development: the organization of the text, necessary to report the results of the above programs, renders it difficult for the reader to obtain the engineering facts and information on the commercial alloys. This defect has been partially rectified by appendix C, *Engineering Data Sheets;* however, if the reader desires specific details, he must dig through the text.

The volume contains a valuable collection of references to the original papers—an indication of the labor involved in preparation. The book is very well produced. The text is clear and there are ample illustrations, which greatly aid in following the text. There are remarkably few typographical errors, and the reviewer would be picayunish by pointing them out.

To sum it up, it is no exaggeration to say that this book is a landmark in the metallurgy of zirconium. It should be of great value to designers, engineers, metallurgists—anyone interested in zirconium.

Aircraft Gas Turbines

By C. W. Smith (John Wiley & Sons, Inc., New York, 1956, xvi + 448 pages, $8.95).

Stressing basic and general principles of the design, installation, and testing of gas turbines and their components for aircraft propulsion, this book presents a sufficiently rounded theoretical picture of gas turbines to make it of value in stationary applications as well. For either application, it will find general background use as an introduction to the subject for reactor designers developing units for use with gas turbines.

Emphasis is on theory and analysis rather than on detailed description. Thus, although the book does not consider reactor uses, thermodynamic and aerodynamic theory presented provide the basis for understanding developments on gas turbines for use with reactors. Component design from the mechanical, structural, and material standpoints are touched on. Applications information and design features described are, of course, principally appropriate to aircraft usage.

After a general introduction to turbines and aircraft propulsion principles, attention is given to gas-turbine cycles and gas dynamics, including flow and energy transfer in ducts, nozzles, diffusers, rotors, and intake and exhaust systems. Compressors, turbines, controls, and accessories are covered—followed by treatments of stresses, materials, general performance factors and installation practices.

BOOKS RECEIVED

Radiation Biology, Vol. 3—Visible and Near-Visible Light, Alexander Hollaender, editor (McGraw-Hill Book Co., Inc., New York, 1956, viii + 765 pages, $10.00). (*To be reviewed.*)

Progress in Nuclear Energy, Series 1, Vol. 1—Physics and Mathematics, R. A. Charpie, J. Horowitz, D. J. Hughes, and D. J. Littler, editors (Pergamon Press Ltd., London, 1956, x + 398 pages, 84s). (*To be reviewed.*)

Atomic Energy and Congress, by Morgan Thomas (University of Michigan Press, Ann Arbor, 1956, x + 301 pages, $4.75). (*To be reviewed.*)

Government Contracting in Atomic Energy, by Richard A. Tybout (University of Michigan Press, Ann Arbor,

1956, xiv + 226 pages, $4.50). (*To be reviewed.*)

Therapeutic Use of Artificial Radioisotopes, Paul F. Hahn, editor (John Wiley and Sons, Inc., New York, 1956, x + 414 pages, $10.00). (*To be reviewed.*)

Advances in Biological and Medical Physics, Vol. 4, John H. Lawrence and C. A. Tobias, editors (Academic Press, Inc., New York, 1956, x + 356 pages, $8.80). The subjects treated in this volume are *X-Ray Diffraction Applied to Crystalline Proteins* (Harker), *The Problem of Information Transfer from the Nucleic Acids to Proteins* (Gamow), *Materials for the Biophysical and Biochemical Study of Cell Division* (Mazia), *Lethal Effects of High and Low Temperatures on Unicellular Organisms* (Wood), *Infrared Spectrometry* (Freeman), *Kinetics of Iron Metabolism* (Huff and Judd), *The Gross Composition of the Body* (Siri), and *A Special Consideration of the Aging Process, Disease, and Life Expectancy.*

The World of Atoms—An Introduction to Physical Science, by J. J. McCue with the assistance of Kenneth W. Sherk (Ronald Press Co., New York, 1956, xiii + 659 pages, $6.50). Intended to stimulate curiosity first and answer questions thereafter, this beginners text has sections headed, *Mechanics, Heat, Foundations of Chemistry, Some Chemical Reactions, Electricity, Solutions, Classification of the Elements, Structure of Atoms, Chemical Binding,* and *The Atomic Nucleus.* It should be interesting to educators to explore the results of presenting a chapter on quantum mechanics to a student who has not yet studied such things as geometrical optics.

Legal Problems in Engineering, by Melvin Nord (John Wiley and Sons, Inc., New York, 1956, viii + 391 pages, $7.50). This book is written as a reference for all engineers or as a college textbook. It combines the textbook and case-study type of presentations. Not intended to permit engineers to dispense with lawyers' services, it should help engineers to avoid legal problems. Cases used as examples are condensed with a minimum of legal jargon.

High Temperature Technology, edited by I. E. Campbell (John Wiley and Sons, Inc., New York, 1956, xiv + 526 pages, $15.00). Sponsored by the Electrochemical Society, this monograph is primarily concerned with temperatures above 1,500° C. Articles by 35 experts are presented in sections describing materials, production methods, and measuring techniques.

Electronics—The Science of Electrons in Action, by A. W. Keen (Philosophical Library, Inc., New York, 1956, 256 pages, $7.50). In descriptive terms, the author presents the principles and applications of electronics. The discussion covers fundamentals, components, circuits, radio, television, computers, and uses in industry.

Kernmomente, by Hans Kopferman (Akademische Verlagsgesellschaft mbH, Frankfurt M., 1956, xvi + 462 pages). This is an up-to-date volume on nuclear moments based on the original edition published 15 years ago. The four chapters, the first of which is by far the longest, are concerned respectively with (1) hyperfine structure of free atoms determined from atomic-beam and optical-interference spectroscopy, (2) nuclear moments of free molecules, (3) high-frequency methods used to study gases, liquids, and crystals, and (4) predictions of nuclear models.

Modern Physics: A Textbook for Engineers, by Robert L. Sproull (John Wiley and Sons, Inc., New York, 1956, 491 pages, $7.75). The author discusses the use of modern physics in understanding processes, instrumentation, and properties of materials.

The Theory of Photons and Electrons, by J. M. Jauch and F. Rohrlich (Addison-Wesley Publishing Co., Inc., Cambridge, 1956, xiv + 488 pages, $10.00). The authors feel that radiation theory has reached a point where a generalized presentation can be made consistent with relativity and quantum mechanics. In outline, this book presents: general principles, free radiation field, free electron field, coupled fields, *S*-matrix, closed systems (photon-electron, electron-electron, photon-photon), open systems (external field), and divergences and renormalization.

Metallurgical Thermochemistry, 2nd ed., by O. Kubaschewski and E. L. Evans (John Wiley and Sons, Inc., New York, and Pergamon Press Ltd., London, 1956, xiv + 410 pages, $10.00). This book is written for the research and applied metallurgical chemist. It includes theory, experimental techniques, methods for estimating values, reference tables, and examples of applications. In this edition, data and methods have been brought up to date.

Chimie Physique Nucléaire Appliquée, by Jacques Errera (Masson et Cie., Paris, 1956, 226 pages, 2.100 fr). The first part of this book discusses the basic principles of nuclear reactions, fission, and fusion. The second part covers radiation detection, safety, and applications.

Rocks and Minerals, by Richard M. Pearl (Barnes and Noble, Inc., New York, 1956, $1.95). This book includes discussions on identifying minerals, prospecting, mining, and industrial uses. Prospecting for and mining uranium are among the topics.

Introduction to Quantum Statistics, by W. Band (D. Van Nostrand Co., Inc., Princeton, 1956, 355 pages, $7.50). Application of statistical mechanics as a tool is emphasized.

ALSO OF NOTE

Radiation food sterilization. A number of publications on this subject are available from the Department of Commerce. "U. S. Army Panel Discussion on Radiation Preservation of Food" (PB 121103, 1956, $0.50) provides discussion of current status and future outlook for food preservation by radiation. "Radiation Sterilization" (PB 111634, 1954, $2.00) reviews literature concerning proteins, lipids, carbohydrates, meats, vitamins, and enzymes. The Quartermaster Food and Container Institute "Bibliographic Series No. 4, Ionizing Radiations—Their Production, Effects, and Utilization (with Special Reference to Food and Packaging Technology)" consists of author index [Part 1 (PB 111635, 1954, $6.75), Part 2 (PB 111636, 1954, $8.00)] and subject index [Part 3 (PB 111637, 1954, $7.25)] and Supplements No. 1 and 2 [author index (PB 1116368, 1955, $11.00) and subject index (PB 1116378, 1955, $4.25)]. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Radioisotope Catalog. The revised catalog lists nearly 100 radioactive preparations—together with specifications and prices—made and distributed

CONTROL OF NUCLEAR REACTORS AND POWER PLANTS

Just Published!

Provides a servo-engineering approach to problem of controlling nuclear reactors. Describes reactor responses in engineering terminology and treats reactors as control elements in larger systems. Presents several systems for research and power producing reactors. Discusses control problems during startup, power level operation, and shutdown. By M. A. Schultz, Atomic Power Div., Westinghouse Elec. Corp. 313 pp. 232 illus., $7.50

Just Published!

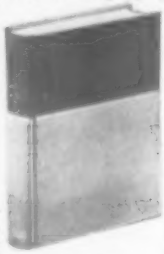
INTRODUCTION TO ELECTRONIC ANALOGUE COMPUTERS

Applies operation and design principles of analog computers to a variety of systems by means of simple, idealistic networks. Components are described, with attention to their inaccuracies, defects, and shortcomings. Covers many newer nonlinear components. Set-up of computers for solving specific problems is shown. Discusses auxiliary apparatus. By C.A.A. Wass, Royal Aircraft Estab., Farnborough, England. 237 pp., $6.50

AN INTRODUCTION TO REACTOR PHYSICS

Just Published!

Covers elementary nuclear physics and theory of thermal reactors, giving background for reactor design. Shielding, instrumentation, and radiation are clearly discussed. Evaluates gas-cooled, graphite moderated, natural uranium reactor. Theory is developed for understanding of problems involved in designing all types of thermal reactors. By D. J. Littler and J. F. Raffle, British Atomic Energy Res. Estab. 196 pp., 76 illus., $4.50



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Information-Classification Schemes. The Special Libraries Association maintains a loan collection at Western Reserve University of subject-matter outlines of specialized fields of knowledge in the natural and social sciences, e.g., chemistry and physics. The collection is being brought up to date and expanded; contributions for all fields are being solicited. Plans are underway to supply microfilm or photostat copies at a nominal fee. *Allen Kent, Chairman, Committee on Special Classifications, SLA, c/o School of Library Science, Western Reserve University, Cleveland 6, Ohio.*

Commercial and International Developments in Atomic Energy. This 598-page book is the proceedings of the Forum meeting held in Washington, D. C., Sept. '55. It includes over 60 papers on such topics as power, test, and research reactors; fuels and source materials; reactor safety; radiation applications; marketing, sales, and investments; activities outside the U. S.; and a review of Geneva papers. Contributors include Lewis L. Strauss, Walter H. Zinn, Gunnar Randers, and Sir John Cockcroft. *Atomic Industrial Forum, 260 Madison Ave., New York 16, New York, $8.50.*

German journals. Two new German monthlies—first in that country in the nuclear field—are now six months old. *Atomkern Energie* (Verlag Karl Thiemig, Pilgersheimerstrasse 38, München 9) takes as its field the scientific, technical, and economic aspects of the subject; *Die Atomwirtschaft* (Verlag Handelsblatt GMBH, Pressehaus, Düsseldorf) concentrates on the nontechnical aspects. As may be expected, both are very much concerned with developments in West Germany, with nuclear legislation, and with government-industry relations. Both emphasize what other countries are doing—the U. S. and U. K. especially. France and India have also been the subjects of special reports recently. Lists of books and articles published in the field are most complete for Germany and provide a valuable key for the foreign reader.

AEC Technical Reports. Two free catalogs of technical reports released by the U. S. Atomic Energy Commission for sale are available. OTS's price list No. 25 supersedes No. 24 issued last August. TID-1901, the AEC's Report Announcement Bulletin lists reports just made available by the stepped-up program of declassification. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Conference of the Academy of Sciences of the USSR on the Peaceful Uses of Atomic Energy (July 1–5, 1955). This English translation of the Russian Conference was made by the Consultants Bureau and sponsored by the AEC. Its four parts cover the sessions on Physical and Mathematical Sciences (AEC-TR-2435 PT. 1, $1.25), Chemical Science (AEC-TR-2435 PT. 2, $1.00), Biological Science (AEC-TR-2435 PT. 3, $1.00), and Technical Science [radiation applications] (AEC-TR-2435 PT. 4, $1.00). *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

The Protection of Workers against Ionising Radiations. This report was submitted to the Geneva conference. It contains sections on radiation injuries, exposure standards, radiation uses, protective measures, uranium mining and processing, and transportation safety. *International Labor Office, 917 15th St., N. W., Washington 5, D. C., $0.50.*

Radioisotopes in Medicine. This 817-page book, issued by the AEC, is the proceedings of a course conducted by the Oak Ridge Institute of Nuclear Studies in 1953. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $5.50.*

Nuclear Science and Engineering. The first issue of this journal of the American Nuclear Society was published in March, 1956. J. G. Beckerley is editor. It is intended for all who are concerned with atomic energy. *Subscription price is $10.00. Academic Press Inc., 125 E. 23rd St., New York 10, N. Y.*

Zirconium—Technology and Economics. This Atomic Industrial Forum publication reports the proceedings of a meeting held Nov. '55. It includes papers and discussion on chemistry and production of metallic zirconium, fabri-

cation, properties, corrosion behavior, alloys, supply of raw and refined materials, commercial products available, future AEC and industrial requirements. *Atomic Industrial Forum, Inc., 260 Madison Ave., New York 16, N. Y., $3.00.*

A Survey of Properties, Applications, and Production Methods of Fused-Quartz Fibers. This 26-page circular (National Bureau of Standards Circular 569), by Nancy J. Tighe, summarizes a literature survey and includes a bibliography. *Government Printing Office, Washington 25, D. C., $0.25.*

Guide to Instrumentation Literature. National Bureau of Standards Circular 567, by W. Brombacher, J. Smith, and L. Van der Pyl, lists over 1,200 references. Individual periodical articles are not listed, but indexes and abstracts on a given subject are indicated. This circular is part of a NBS research and development program sponsored by AEC, ONR, and Air Research and Development Command. *Government Printing Office, Washington 25, D. C., $1.00.*

Bibliography of Research on Deuterium and Tritium Compounds, 1945-1952. NBS Circular 562, by L. Brown, A. Friedman, C. Beckett, lists 2,482 references. It contains author, subject, and compound indexes. *Government Printing Office, Washington 25, D. C., $0.50.*

Microfilmed Reports. Microfilm collections are available of unclassified AEC reports and categories as listed in *Nuclear Science Abstracts.* Prices are $0.35 for single card containing 40 pages of micro-copy to $0.28 per card for 500 or more cards. *Clark, Hitchcock and Assoc., Microform Publishing Div., 1115 17th St., N. W., Washington 6, D. C.*

Bibliography of Available Digital Computer Codes for Nuclear Reactor Problems (AECU-3078). This ready listing of reactor digital computer codes, presently available or in preparation, enables the engineer or physicist to find the codes most helpful in his work. The codes are for digital computers of the size of the card programmed calculator (CPC) or larger. Tabulation gives title, cognizant engineer, laboratory, computer, problem status, category, geometry and dimensions, typical computing time, parameters solved, problem description, limita-

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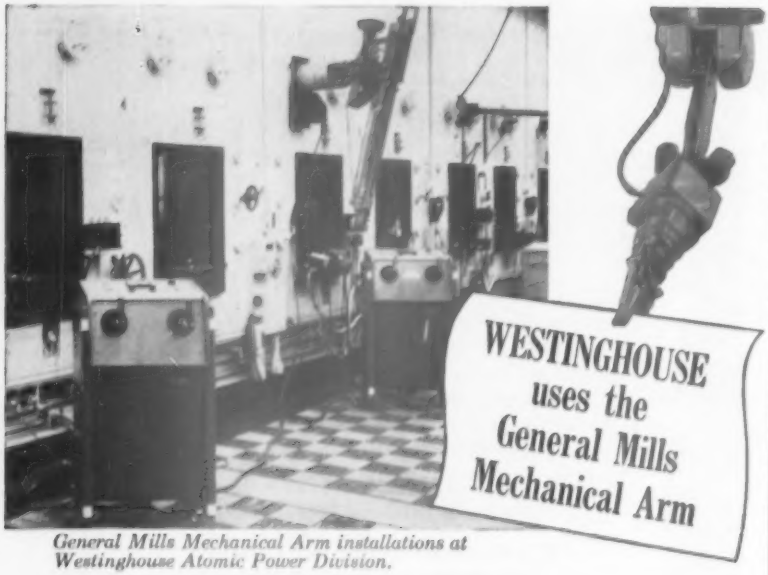

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tions of the code, and references. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $0.60.*

Copper Wire Tables, 4th ed. In this new edition of the National Bureau of Standards Circular 31, the tables have been extended to 50 gage and 200° C. Data is in English and metric units. Formulas are provided to compute data for any size wire. *U. S. Government Printing Office, Washington 25, D. C., $0.30.*

Geological Survey Bulletins. Three bulletins report work done on behalf of the AEC: Uranium-Bearing Nickel-Cobalt-Native Silver Deposits, Black Hawk District, Grant County, New Mexico (Bulletin 1009-K, $0.65); Radioactive Deposits in New Mexico (Bulletin 1009-L, $0.70); and Botanical Prospecting for Uranium on La Ventana Mesa, Sandoval County, New Mexico (Bulletin 1009-M, $0.15). *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

Technical Digests. This monthly publication of the OEEC presents digests in English of articles appearing in European technical and industrial journals. It is primarily for those interested in manufacturing and production. The illustrated monthly averages 140 pages. *Organization for European Economic Cooperation, Publications Office, 2000 P St., N. W. Washington 6, D. C., $24.00 annually, $2.50 per copy.*

The Initiation of Chemical Reactions by Gamma and Other Ionizing Radiations. This monograph (TID-8005) by David S. Ballantine discusses radiation interaction with matter and its application to inducing reactions, such as polymerization. It is sponsored by the Industrial Information Branch of the AEC. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $0.15.*

ASTM Standards. The 1955 edition has over 11,000 pages and includes more than 2,150 standard specifications, tests, and definitions for materials. It is issued in seven parts. Following are the parts and the number of standards in each and the price of each: Ferrous Metals (315, $13.50); Nonferrous Metals (270, $11.00); Cement, Concrete, Ceramics, Thermal Insulation, Road Materials, Waterproofing and Soils (477, $13.50); Paint, Naval

Stores, Wood Cellulose, Wax Polishes, Sandwich Building Constructions (323, $11.00); Fuels, Petroleum, Aromatic Hydrocarbons, and Engine Antifreezes (242, $11.00); Electrical Insulation, Electronic Materials, Plastics and Rubber (300, $13.00); Textiles, Soap, Water, Paper, Adhesives, and Shipping Containers (354, $11.00). The complete set is $84.00. *American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.*

Table of Hyperbolic Sines and Cosines, x = 2 to x = 10. This table in the National Bureau of Standards Applied Mathematics Series 45 is an addition to the Applied Mathematics Series 36, Tables of Circular and Hyperbolic Sines and Cosines for Radian Arguments. Data were calculated on the NBS SEAC computer. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.55.*

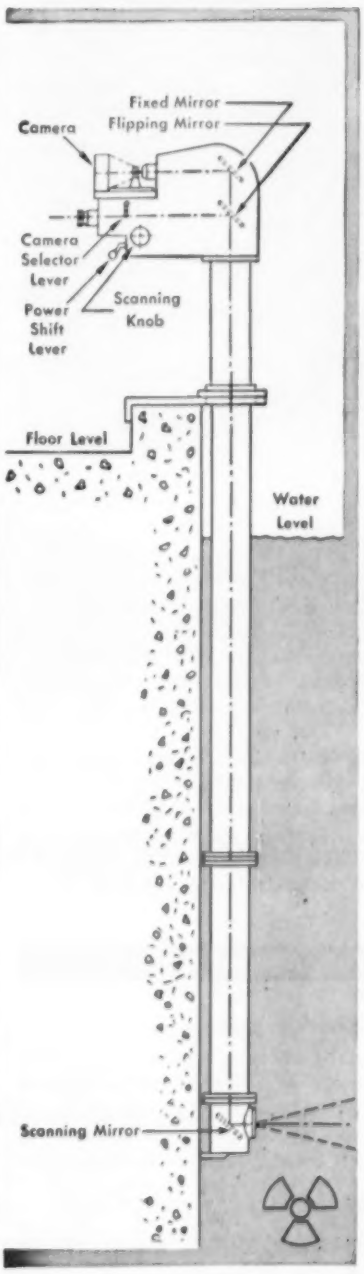
Possibilities of Action in the Field of Nuclear Energy. This OEEC publication was drawn up by a working party of the OEEC council preliminary to discussion by the member-country representatives. Topics considered are energy requirements, the role of OEEC, member-country cooperation, security, and procedure. *Organization for European Economic Co-operation, Publication Office, 2002 P St., N. W., Washington 6, D. C., $1.00.*

Engineers' Job Directory. This 88-page directory describes 236 firm and their requirements. *Decision Inc., 1483 First National Bank Bldg., Cincinnati 2, Ohio, $3.25.*

Standard X-Ray Diffraction Powder Patterns. NBS Circular 539, vol. 5, by H. Swanson, N. Gilfrich, G. Ugrinic, presents 45 patterns, which revise 74 corresponding patterns filed with ASTM, as well as 5 not previously filed. *Government Printing Office, Washington 25, D. C., $0.45.*

Encyclopedia of American Associations. More than 7,000 trade, professional, and social organizations are listed, including address, principal officer, and general description. Cross indexing provides multiple listing by name or any key word. Supplemental sections provide subject and functional groupings and semiannual notice of listing changes. *Gale Research Co., 247 Kenworth Rd., Columbus 14, Ohio, $15.00.*

UNDERWATER PERISCOPE



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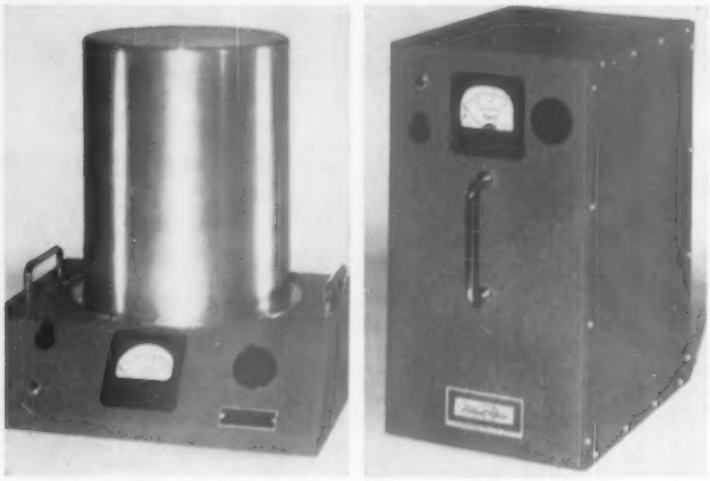
PRODUCTS AND MATERIALS



Fast-Neutron Survey Meter Uses Phosphor-Coated Sphere

Thin plastic sphere with inside phosphor coating is sensitive element of the Egghead, fast-neutron survey meter. Unit is for health hazard survey.

Polyethylene sphere (7-in. o.d., 6¾-in. i.d.) has ZnS phosphor. Knock-on protons produce light pulses, which excite Dumont 5819 photomultiplier. Result is nondirectional pattern with exception of dimple where photomultiplier is inserted into sphere. Dimple is at bottom of laboratory models (left) and to the back of portable model.

Instrument will read as little as 1 count/8 sec, which indicates a field delivering 0.19 mrep/hr to biological material. Adjustable discriminator permits elimination of gamma background. Three ranges read 7.5, 75, 750 mrep/hr full scale. Phone jack provides audible detection. Battery-operated portable, battery-operated laboratory, and line-operated laboratory models are available.—National Radiac, Inc., 475 Washington St., Newark 2, N. J.

ELECTRONIC INSTRUMENTS AND APPARATUS

Repeat-Cycle Timer

Electronic timer provides adjustable intervals from 0.1 to 200 sec. Automatic operation with one cycle initiating next.—G. C. Wilson & Co., 1915 Eighth Ave., Huntington, W. Va.

Random pulser

Transistorized, portable random-pulse generator Model-422 delivers pulses at a controlled rate of from 10 to 1,000/sec. Operates for over 100 hr from 4 standard flashlight batteries.—Universal Atomics Corp., 19 E. 48th St., New York 17, N. Y.

Tube-test adapter. Designed for insertion between tube and socket, adapter permits switching of test lead without disturbing tube. Available for 7-pin miniatures, 8-pin octals, and 9-pin novals.—Vector Electronic Co., 3352 San Fernando Road, Los Angeles, Cal.

Non-overloading amplifier. Model 215 is designed for new scintillation-counting techniques.—Atomic Instruments Co., Cambridge 39, Mass.

Audio oscillators. Lighter in weight and housed in new smaller cabinets are three R-C audio oscillators. Model 201-C has frequency range 20–20,000 cps, provides 3 watts into 600 ohms. Can be used as low-source-impedance device or with output attenuator with four 10-db steps. Model 200J covers 6 to 6,000 cps with frequency calibrations good to ±1%, designed for 10 volts into 600 ohms. Model 202C has frequency range 1–100,000 cps and provides 10 volts into 600 ohms or 20 volts open circuit.—Hewlett-Packard Co., 275 Page Mill Road, Palo Alto, Cal.

Count-rate meter. Model DM12 precision counting-rate meter is designed to count pulses from G-M and scintillation detectors, single-channel pulse-height analyzers, etc. Pulse-height discriminator operates from −10 to 20 volts. Twenty counting-rate ranges are available.—Detectolab, Inc., 6544 N. Sheridan Rd., Chicago 26, Ill.

Transformer substitute. Magnetic component is offered to replace miniature broadband pulse transformers. Manufacturer claims improved wave form, better impedance match, lower losses, higher output, higher voltage ratings.—Pulse Engineering, 2431 Spring St., Redwood City, Cal.

Electronic counter. Model WE-120 electronic counter has digital presentation. Range, 10 to 100,000 cps; count, 100,000 units, 5 decades; sensitivity, 50 millivolts.—Westport Electric, 149 Lomita St., El Segundo, Cal.

Products Index

Electronic Instruments and Apparatus 112

Laboratory Instruments and Apparatus 114

Radioactivity Materials and Apparatus 114

Literature Available 116

Industry Notes 118

MODERN BUSINESS

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LABORATORY INSTRUMENTS AND APPARATUS

Unusual Conveyor is Free of Contamination Problems

This device meets the problem of how to take things in and out of a "hot" area or a neutron flux without bringing out undesirable contamination in the conveyor system. Monoflo Conveyor consists of flexible steel cable with spiral outer surface. Cable is rotated in open-topped casing with top protruding.

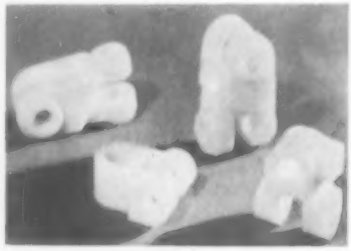
Loads can be up to 15 lb, speeds to 12 ft/min, and system can be arranged so that load is picked off, dropped off, or accumulated at end of line. Standard fittings permit paths with horizontal and vertical curves.—M-H Standard Corp., 513-521 Communipaw Ave., Jersey City 4, N. J.

Monochromatic Source

High-pressure mercury-vapor lamp operates on 115 volts, 60 cycles for use with filters to provide monochromatic light at the wave lengths of the mercury lines. Housing contains rotatable monochromatic filter turret for four different filters or combinations. Light source is supplied with filters in turret.—Phoenix Precision Instrument Co., Inc., 3803-05 N. Fifth St., Philadelphia 40, Pa.

Portable Hood

New equipment is said to eliminate fumes and other chemical-operation byproducts at the source. Equipment permits recirculation of air; automatically processes acid effluent to prevent drain pipe corrosion.—Yerzley and Co., 744 Broad St., Newark 2, N. J.



Cold-Machined Plastics

Cryogenic process permits machining plastics to unusual tolerances. Conventional automatic machinery is used. Process is effective for large plastic parts as well as miniature and sub-miniature pieces.—Standard Automation Products, 1738 Ridgeway Rd., Havertown, Pa.

Transducer controls. Model C4B provides in one cabinet ten channels of excitation and bridge-balance controls for oscillographic recording, and accepts three basic types of transducers, intermixed, through the use of plug-in control units—magnetic reluctance, strain-gage, and potentiometer. Contains stepping switch for automatic sequential calibration of all recording channels. Measures 18 × 11 × 8 in., weighs 35 lb.—Pace Engineering Co., 6914 Beck Ave., N. Hollywood, Cal.

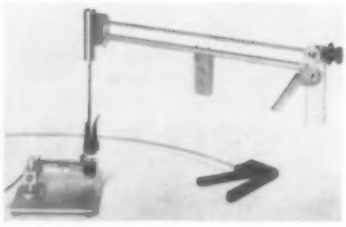
Dust precipitators. Electrostatic precipitators use an electronically controlled rapper system to continuously remove collected dust.—Synthane Corp., Oaks, Pa.

Gas-flow Standard. Model-40 gas-flow calibrator is a dual-range instrument with two high-precision all-metal meter elements that may be individually connected to a single manometer. Reproduceability is said to be better than 0.1%, and accuracy is guaranteed 0.25% of full-scale flow. Standard ranges are from 0.3 to 1,000 lit/min.—National Instruments Laboratory, Inc., 6108 Rhode Island Ave., Riverdale, Md.

Neutron Absorption Analyzer

Using the principle of neutron absorption, this instrument detects and measures an element having a high absorption cross section in a sample or mixture of elements. No chemical treatment is required; the analysis is nondestructive and rapid.—Reed-Curtis Nuclear Industries, Inc., Nuclear Div. of American Electronics, Inc., 655 W. Washington Blvd., Los Angeles 15, Cal.

RADIOACTIVITY MATERIALS AND APPARATUS

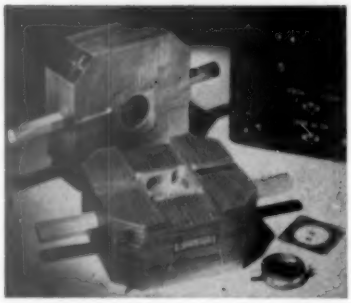


Remote Handlers

Filter for radioactive precipitates, remote vial opener (above), and remote micro-pipettor are available.—Nuclear Science Associates, 21 Dunvale Rd., Towson 4, Md.

Van de Graaff generator. Three-million-volt particle accelerator, weighing 9 tons, is designed to produce nearly all the fundamental radiations—electron, X-ray, positive ion, neutron. Rated at 3,000 watts, it can be mounted in vertical or horizontal position.—High Voltage Engineering Corp., 7 University Rd., Cambridge 38, Mass.

New radiochemical. Histamine (2-ring-C-14) dihydrochloride is available at activity of 1 mc/millimole. Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.



Sample Changer

Shielded manual sample changer reduces background by factor of 2–4. Designed for two facing tubes.—Anton Electronic Laboratories, Inc., 1226 Flushing Ave., Brooklyn 37, N. Y.

Cobalt-60 sources. Individually calibrated Co^{60} gamma-ray sources are approximately ¼ in. dia × ½ in. long. Special sources will be fabricated to customer specifications. Standard sources are available in various sizes from 1 mc to 2,000 mc.—Nuclear-Chicago, 333 W. Erie St., Chicago 10, Ill.

Radiation tags. Plastic-sealed tags with the radiation warning symbol are impervious to wear, tear, dirt, moisture, and oil.—Identification Service Corp., 144 W. 46th St., New York 36, N. Y.

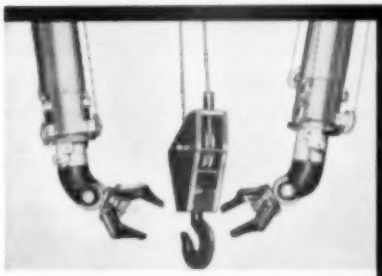
Scaler, probe cart. Mobile stands for detection probes enable radiotherapists to hold probes at any desired point over the patient.—The Atomic Center, 489 Fifth Ave., New York 17, N. Y.

Manipulator

Niptongs, mechanical manipulator is for handling any hot, caustic, or radioactive material of small dimensions. Available in 12, 24, 36, 48-in. lengths.—The Atomic Center, Inc., 489 Fifth Ave., New York 17, N. Y.

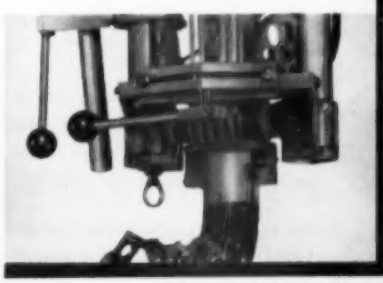
CRL manipulators
plus
CRL accessories
equals
versatility

One of the important characteristics leading to the choice of Master-Slave Manipulators for most hot cells currently being constructed is versatility. The wise buyer who obtains manipulators from Central Research Laboratories will be happy to know that a wide variety of accessories are available from CRL to augment this versatility.



Flexible Booting protects slave end of manipulator from dust, contamination, and corrosion. Restricted gas-flow seal possible. Does not interfere with any of the manipulator's natural movements.

Load Hook available for CRL Model 8 may be remotely attached or detached and permits a vertical lift of 60 pounds.



Cranes and Hoists. Lifting and moving of heavy loads in hot-cell areas may be accomplished by remote-control cranes and hoists specially designed and manufactured by CRL for use with Master-Slave Manipulators.

Special Purpose Tongs. For repetitive or highly specialized operations, specially-designed, remotely-interchangeable tongs can be supplied to increase speed and ease of operation.

Motion Locks enable one to position rigidly in space any object which the manipulator can handle. Locking grip is standard equipment on all models. Locks for all other rotation, translation, and elevation motions are available as extra accessories.

For more information on special applications of CRL Master-Slave Manipulators, phone or write today to

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"LINDE" M.S.C. rare gases are the purest obtainable

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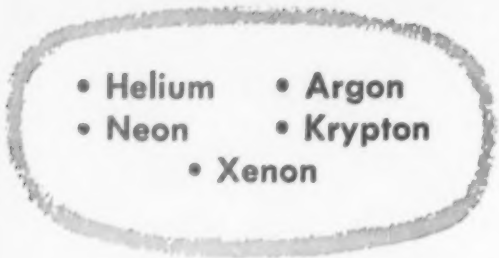

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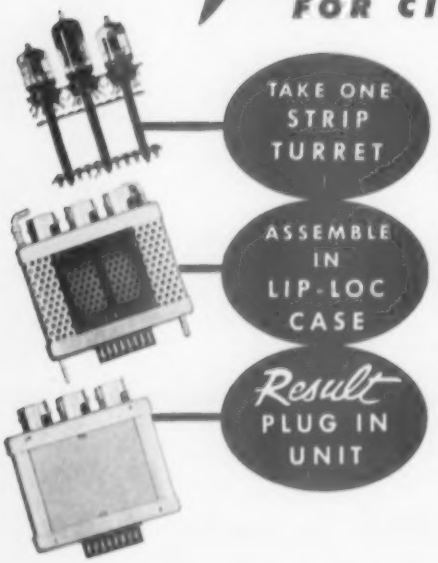

Choice of Deck, or Wall type strips in many sizes offer miniaturization, accessibility, ease of assembly and adaptation to semi-automatic machinery.

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LITERATURE AVAILABLE

Cosmic-ray counter. March issue of RCL Counter has articles on performance and specifications of cosmic-ray counters and an evaporator feeder.—Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.

Power transmission equipment. The Zero-Max infinitely variable speed transmission is fully described, with application and installation suggestions, in new catalog. 12 p.—Revco, Inc., 2 East Franklin Ave., Minneapolis 4, Minn.

Laboratory instruments. A new RF leak detector, automatic spectrophotometers, pH electrode, and other laboratory and industrial equipment are described in 8-page bulletin.—Beckman Div., Beckman Instruments, Inc., Fullerton, Cal.

Laboratory glassware. Catalog lists standard and special laboratory glass equipment. 206 p.—Laboratory and Pharmaceutical Sales Dept., Corning Glass Works, Corning, N. Y.

Photocells and sun batteries. Technical information on selenium photocells and sun batteries is given in new booklet. 58 p.—International Rectifier Corp., Production Information Dept., El Segundo, Cal.

Recording and control. Instruments for recording and controlling are described along with sensing elements and applications in 64-page bulletin P1245A.—The Bristol Co., Waterbury 20, Conn.

Radiation leak detector. Radiflow leak-detection system using radioisotopes to inspect hermetically sealed containers is described in brochure 7071.1. 82 p.—Reed-Curtis Nuclear Industries, Inc., Division of American Electronics, Inc., 655 W. Washington Blvd., Los Angeles 15, Cal.

Uranium prospecting. Brochure describes model 8612L counter for uranium prospecting. 4 p.—Nuclear-Chicago, 223 W. Erie St., Chicago 10, Ill.

Radiology. Spring issue of "Your Radiologist" describes practice of radiology.—Commission on Public Relations, American College of Radiology, Suite 1925, 20 N. Wacker Dr., Chicago, Ill.

Instrumentation. Handbook describes line of precision instrumentation: recorders, VTVM's, precision phase standards, phase meters, oscillators, etc.—Acton Laboratories, Inc., 533 Main St., Acton, Mass.

Counters. Six-page brochure describes scintillation counters. Four-page brochure describes neutron and cosmic-ray counters.—N. Wood Counter Laboratory, 5491 S. Blackstone Ave., Chicago 15, Ill.

Magnetic spectrometer. Recent issue of Perkin-Elmer Instrument News includes article on new nuclear-magnetic-resonance spectrometer.—Perkin-Elmer Co p., Norwalk, Conn.

Radioactivity instrumentation. 12-page catalog and several 2-page brochures describe instrumentation for the radioactivity laboratory.—Nucleonics Co. of America, 497 Union St., Brooklyn 13, N. Y.

Test instruments. Electromagnetic pumps, ionization chambers, control devices, neutron proportional counters, radiation monitors, scintillation counters are among devices described in 40-page "testing instruments reference book."—General Electric Co., Schenectady 5, N. Y.

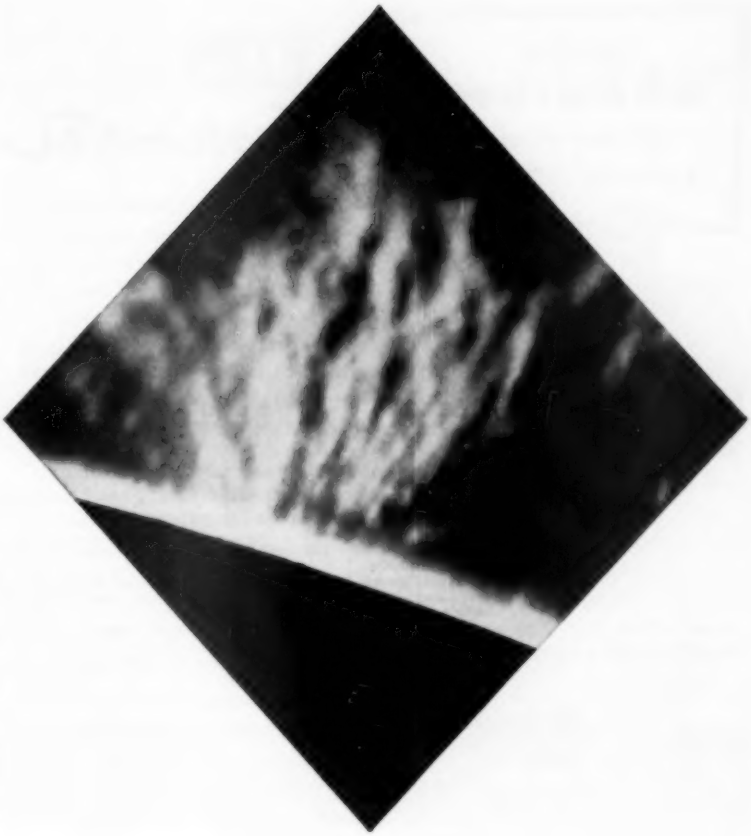
Well counter. Model CS-600 well-type scintillation counter is described. 2 p.—NRD Instrument Co., 6425 Etzel Ave., St. Louis 14, Mo.

Tracer research. Engineering bulletin includes article on radioactive tracers in engine research.—Thompson Products Inc., 23555 Euclid Ave., Cleveland 17, O.

Nuclear instruments. Technical bulletin PL-1 describes multiplier tubes, G-M tubes, cosmic-ray tubes, survey meters, and scalers. Technical bulletin N-2, N-9, describes G-M tubes. 2 p. each.—Nucleonics Co. of America, 196 Degraw St., Brooklyn 31, N. Y.

Pumps. Bulletin AC 56 describes rotary displacement pump line for corrosive and hazardous fluids. 4 p. —Eco Engineering Co., 12 New York Ave., Newark 1, N. J.

Electroplating. The Dalic Process, a method of localized and selective plating new in the United States, is described in articles available on request.—Marlane Development Co., Inc., 153 E. 26 St., New York 10, N. Y.



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REPRESENTATIVES IN PRINCIPAL CITIES

Radiation equipment. Catalog with die-cut pages indicates methods to interconnect basic units to make various types of radiation-laboratory instruments. 62 p.—Tracerlab, 130 High St., Boston 10, Mass.

Shadow-free illuminator. Device to produce shadow-free illumination, especially useful for engineering and technical photographs and visual inspection, is described. 4 p.—Hinelight Corp., 2538 John St., Fort Wayne, Ind.

Radiation instruments. Several brochures describe radiation-measuring instruments. Condensed catalog describes detection instruments for alpha-, beta-, gamma-, and X-radiation. Brochures describe medical and research instruments, personnel and area monitors, laboratory and field-survey meters, civil defense instruments.—Victoreen Instruments Co., 5806 Hough Ave., Cleveland 3, O.

Plastics. Fluorocarbon plastics for printed circuitry are described with data on proposed types of physical and chemical properties, laminate properties, electrical properties, and design considerations. 2 p.—International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.

INDUSTRY NOTES

▶**Packard Instrument Co.,** LaGrange, Ill. has appointed **Atomic Associates, Inc.,** (NU Mar. '56, p. 115) Northeastern sales representative.

▶**Farrel-Birmingham Co.,** Ansonia, Conn., has moved its Chicago office to 10725 South Western Ave.

▶**Electro-Pulse, Inc.,** has appointed **Electro Sales Associates,** 281 E. 216th St., Euclid 23, Ohio as their sales representative in the Ohio-Michigan area.

▶**James E. Wallen** has become treasurer of **Nuclear Corp. of America, Inc.**

▶**James H. Bly** will devote his efforts to Van de Graaff generators as a new member of the sales division of **High Voltage Engineering Corp.,** Cambridge, Mass.

▶**Atomic Instruments Co.** and **Baird Associates, Inc.** now operate under the name **Baird Associates-Atomic Instrument Co.** The merger, effective June 1, was ratified by stockholders on May 7.

▶**Nucleonics Co. of America** announces the appointment of **Atomic Associates, Inc.**, as sales representatives for their line of G-M tubes, cosmic-ray tubes, and film-badge services.

▶**Electro-Mec Associates,** 109 E. Nine Mile Road, Ferndale, Mich. are now sales representatives in Michigan for the **Millivac Instruments Corp.,** Schenectady, N. Y.

▶**The M. W. Kellogg Co.** has consolidated its New York offices at 711 Third Ave. between 44th and 45th Sts.

▶**Nuclear Corp. of America, Inc.,** has acquired **Isotope Specialties Co.** of Burbank, Cal., in exchange for 47,991 shares of Nuclear's Class A stock.

▶**Robert L. Deming** is head of the new nucleonics research section of **Stromberg-Carlson** Division of General Dynamics. **Matthew P. Tubinis** and **Thomas T. Thwaittes** are on the staff.

▶For the six months ended with February, **Nuclear-Chicago** has reported net earnings after provision for federal income taxes of $97,264 compared with $44,003 for the corresponding six months a year ago.

▶**Stuart F. Louchheim Co.** has acquired controlling interest in **Nuclear-Electronics Corp.** of Philadelphia. **John S. Wagenfeller** will be president of the new combined company.

▶**Standard Uranium Corp.** reports a net profit of $588,521 for its first year of operation ended Dec. 31.

Continued from p. 104

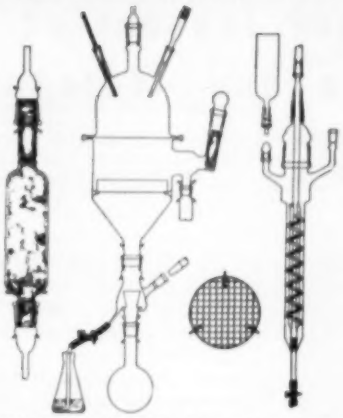
cases of a more routine nature.

It is my hope that this letter will help in correcting whatever misunderstandings exist of this event. Above all, I hope that it will help those interested in atomic energy to understand the problems faced by experimenters. It would be most unfortunate, indeed, if conjecture, speculation, and criticism in news media were to act to discourage those responsible for promoting our atomic program from undertaking any problem whose solution could lead to progress.

W. H. Zinn, Director
Argonne National Laboratory

Now from Delmar Scientific . . .

METABOLISM CAGE SYSTEM FOR RATS



This all-glass cage system is used to study excretion pattern in urine, feces and expired air of rats injected with carbon-14 labeled compound. Ancillary equipment shown in diagram is also designed to work with cage systems for mice.

OPERATION: Column at left dries room air and frees it of CO_2. Center column houses the rats; air enters cage at top and is drawn off at bottom. Column at right absorbs CO_2 from rat chamber which may be recovered for radioassay.

EASILY CLEANED: Separator and stainless steel floor are removable for cleaning while the absorption towers are washed without disassembling.

PRICE: . . . available in various sizes . . . price complete $202.50

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Refer to Dr. L. J. Roth's Article; April 1956 Nucleonics.

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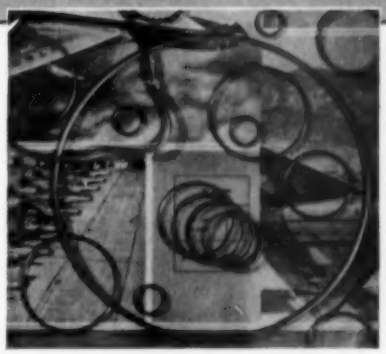

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NEWSMAKERS

Walter H. Zinn, retiring director of Argonne National Laboratory, is serving as a part-time consultant to the Joint Congressional Committee on Atomic Energy until July 1, 1956.

J. G. MacHutchin, formerly chemical production manager in the commercial products division of Atomic Energy of Canada, Ltd., has been named director of research on radioactive materials at the Bloomsburg, Pa., laboratories of U. S. Radium Corp.

Col. John R. Hood, Jr., has been selected to head the nuclear research and engineering facility at Wright Air Development Center, Wright-Patterson AFB, Ohio. **Maj. Paul J. Sykes** is deputy chief.

New York Shipbuilding Corp. has engaged **Howard I. Kraig,** reactor engineer, from Argonne National Laboratory.

AEC has named **Robert E. Hollingsworth** as assistant general manager for administration, succeeding **J. L. Kelehan** who resigned to become vice-president of Ryan Industries, Detroit. Hollingsworth has been with AEC since 1947.

Ugo Fano, chief of the nuclear physics section of the National Bureau of Standards and an authority on the penetration and diffusion of radiation through matter, has been granted a Rockefeller Public Service Award that will permit him to complete a book on quantum physics for nonphysicists, and to spend the 1956 academic year teaching at the University of Rome.

Chemist **Alfredo Landoni** and engineer **Ernesto Schonfeld** of the Argentine Atomic Energy Commission are taking a four-months' course at the University of Pennsylvania in peaceful applications of nuclear energy; thereafter they will take the six-month course at the Argonne School of Nuclear Science and Engineering.

General Atomic division of General Dynamics has named **Robert B. Duffield** of the University of Illinois to head the chemistry program at the new Torrey Pines laboratory near San Diego. **William I. Thompson,** chemical engineering consultant to AEC's research division, will be chief of process engineering. **Vincent W. Jones** will head engineering and construction on the new lab; **Sam J. Farmer** will be counsel for General Atomic; **J. Frank Behan** comptroller for GA, and **James S. Quidor** head of administrative services.

John G. Seiler, president of Tube Turns, Louisville, Ky., has been named to the nuclear energy group of the Southern Regional Education Board studying peacetime nuclear applications in the South.

A. A. Danilin of the USSR, **B. Guilmet** of France, **P. J. Meade** of the UK and **A. I. Wexler** of the U. S. Weather Bureau have been constituted a panel of experts by the World Meteorological Organization to study the movement of radioactive waste products in the atmosphere.

Harvey de Covnick, formerly with North American Aviation, has been named nuclear reactor systems engineer at Radiation Counter Laboratories, Nucleonic Park, Skokie, Ill.

Lothar W. Nordheim, theoretical physicist and early nuclear researcher at Oak Ridge, has joined the staff of General Atomic's new San Diego laboratory. Nordheim has been professor of physics at Duke University since 1937; he went to Oak Ridge in January 1944 and was director of the physics division at ORNL from 1945 to 1947.

Oak Ridge Institute of Nuclear Studies has appointed **R. J. Stephenson,** professor of physics at the College of Wooster, Wooster, O., as technical director of summer training for the Oak Ridge science demonstration lecture program.

K. H. Sun, nuclear physicist at Westinghouse, has been promoted to advisory engineer in charge of the company's radiation and nucleonics laboratory.

D. F. Cope, formerly chief of the research branch at AEC's Oak Ridge Operations Office, has been named deputy director of the research and development division. **E. E. Sinclair,** formerly assistant chief of research branch, moves up to head that unit.

Perry R. Roehm, executive vice president of Norden-Ketay Corp., was elected president of the company to succeed **Morris F. Ketay,** who is retiring after 12 years as president. He will remain on the board of directors.

Lloyd R. Zumwalt, operations vice-president of Nuclear Science and Engineering Corp., and **Charles D. Coryell,** professor of chemistry at MIT and an associate scientist of NSEC, have been elected directors of the company.

Clifford G. Shull, formerly chief physicist at Oak Ridge National Laboratory and now at Brookhaven National Laboratory, will join the MIT faculty as a full professor July 1. He is noted for his work in solid state and neutron physics and neutron and X-ray diffraction. Also named a full professor at MIT is **Jule G. Charney** of the Institute for Advanced Study, Princeton.

Cyril L. Comar, chief of biomedical research at Oak Ridge Institute of Nuclear Studies, has been named a technical collaborator of the U. S. Department of Agriculture Research Service's Southern Utilization Research Branch.

Alfred O. Nier, chairman of the physics department at the University of Minnesota; **Harvard L. Hull,** president of Farnsworth Electronics Co.; and **Philip H. Nason,** St. Paul banker, have been named directors of Central Research Laboratories Inc., Red Wing, Minn.

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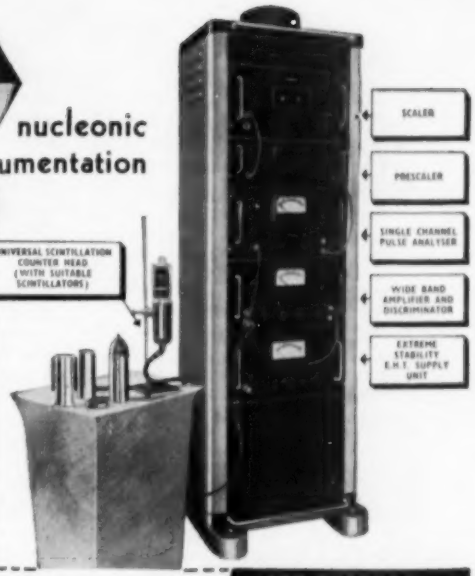

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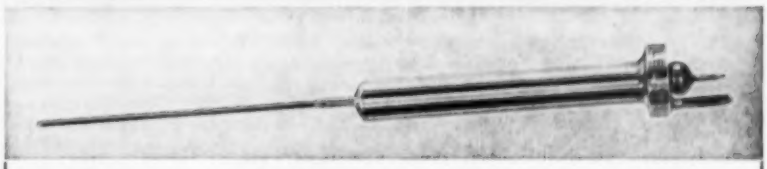

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NUCLEAR CALENDAR

June 16–23—Fifth World Power Conference, Vienna. Development of power production and utilization, waste purification, international collaboration. Contact Engineers' Joint Council, 33 W 39, NYC 18.

June 21–23—Society of Nuclear Medicine, annual meeting, Salt Lake City. Contact R. G. Moffat, 2656 Heather St., Vancouver 9, B. C.

June 24–27—Health Physics Society, annual meeting, Ann Arbor, Mich. Contact Elda Anderson, USAEC, Oak Ridge, Tenn.

June 25–26—National Conference, Uranium & the Atomic Industry (Atomic Industrial Forum and Denver Research Institute), Denver (*Cosmopolitan Hotel*). Contact D. J. Scherer, AIF, 260 Madison Ave., NYC 16.

June 25–27—Symposium, High Temperature: A Tool for the Future (Stanford Research Institute and University of California), Berkeley, Calif. Contact Nevin K. Hiester, SRI, Menlo Park, Calif.

June 25–29—Am. Soc. for Engineering Education, annual meeting, Ames, Iowa. Contact W. Leighton Collins, Univ. Illinois, Urbana, Ill.

June 25–29—Conference on Nuclear Chemistry (Gordon Research Conferences of the Am. Assn. for Advancement of Science), Kimball Union Academy, Meriden, N. H. Contact W. G. Parks, University of Rhode Island, Kingston, R. I.

July 2–6—Conference on Chemistry and Physics of Isotopes (Gordon Research Conference), Kimball Union Academy, Meriden, N. H. Contact W. G. Parks (see above).

July 2–7—International Nuclear Physics Congress, Amsterdam. High- and low-energy reactions. Contact Netherlands Society of Physics, Bijlhouwerstraat 6, Utrecht.

July 9–13—Conference on Radiation Chemistry (Gordon Research Conference), New Hampton School, New Hampton, N. H. Chemical utilization of nuclear energy; kinetics of radical reactions; radiation chemistry of aqueous systems, gases and polymers. Contact W. G. Parks (see above).

July 9–Aug. 10—Summer institute for college and university science teachers, sponsored by National Science Foundation at Oak Ridge Institute of Nuclear Science, Oak Ridge, Tenn. Contact ORINS.

July 22–28—Eighth International Congress of Radiology, Mexico City. Symposia on radiodiagnosis, radiotherapy, radiation physics, X-ray technology, radiobiology. Contact José Noriega, Box 21964, México 7, D. F.

Sept. 25–27—Atomic Industrial Forum, annual meeting, Chicago (*Morrison*). Second annual Trade Fair of the atomic industry **Sept. 24–28**, Chicago Navy Pier. Contact D. J. Scherer, AIF (see above).

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Russian Thermonuclear Experiments (Continued from p. 43)

discharge-tube axis. Thus, the work of the electrodynamic forces is not expended in raising the temperature but in imparting kinetic energy to the converging plasma layer. At this stage the discharge tube operates as a peculiar type of accelerator in which the particles are driven by the magnetic field. Since charged particles, irrespective of sign, will move with the same velocity, the kinetic energy acquired by the ions will be quite large. But the kinetic energy of the electrons practically will not change in virtue of the small mass of these particles.

From the viewpoint of gas dynamics, the contraction process should be considered as a phenomenon in which a cylindrical shock wave converging towards the axis is produced in the plasma. At first, the gas located before the inner wave front is not ionized. When the wave begins to move the gas is carried along together with the charged particles of the plasma and its atoms simultaneously become ionized. The amount of matter that begins to move gradually increases and the total amount of ions and electrons in the plasma increases rapidly. The duration of the contraction phase can be determined by calculating the velocity acquired by the contracting gas. It was found to be approximately proportional to $(M/V_0^2)^{1/4}$, where M is the mass of gas per unit length of discharge tube and V_0 is the initial voltage. This is exactly what one finds experimentally for the interval between breakdown and appearance of the first kink in the current oscillogram.

The final stage of cumulative contraction sets in when the plasma accelerated by the magnetic field reaches the axis. At this moment a great part of the energy of ordered motion changes into heat and the pressure and plasma temperature sharply increases. During maximum contraction, the plasma temperature may be of the order of $10^{6\circ}$ C.

> ***"Kurchatov apparently only guesses his temperature of $10^{6\circ}$ C and does not indicate how he arrived at it. Our own method (NU, Feb. '56, p. 42) gives much too low values for hydrogen, which is transparent even at our highest temperatures. More important than this measurement question is whether there is a true Boltzmann (i.e. thermal) distribution of energies. I doubt that the short time interval in which the cylindrical compression wave meets at the axis of the tube is long enough (several tenths of a microsecond) to establish temperature equilibrium at this point. Certainly the neutron production itself is associated with strong directed accelerations, rather than any thermal distribution of energy"—Heinz Fischer, Cambridge Research Center.***

The nature of the processes occurring during maximum contraction are not very clear, but after maximum cumulation a diverging shock wave should appear to drive the plasma towards the walls. Inside the outgoing wave there should be a rarified zone. Under the action of electrodynamic forces that tend to compress the current, the outgoing wave should be decelerated abruptly and a new phase of contraction should ensue. This stage differs from the first in that the density in the inner region of the discharge is small and the gas in this region is probably almost completely ionized.

Acceleration mechanism. As a result, during the second contraction, conditions are produced that are favorable for accelerating in the longitudinal electric field a certain group of ions and electrons located near the discharge axis, i.e., in the region in which the magnetic field is small.

One may note here a certain analogy with the accelerating mechanism proposed by Fermi in his theory of origin of cosmic rays.* A plasma of high conductivity will move together with its magnetic field, and with respect to particles located in the inner zone it will be equivalent to a converging magnetic wall from which the enclosed electrons and ions repeatedly will be reflected, their energy increasing after each reflection.

Acceleration of ions and electrons in the longitudinal electrical field near the discharge axis is possibly the explanation of appearance of neutrons and penetrating X-rays. The electric field strength during the second contraction may be very high. It can exceed the instantaneous external voltage applied to the discharge tube by many times.

> ***Kurchatov does not fully explain the acceleration mechanism but it may be as follows: As in the Fermi mechanism ions below a certain energy are turned around by the magnetic field in the contracting plasma. Simultaneously their motion relative to its magnetic field results in an effective longitudinal electric field that accelerates them in the direction of the applied electric field. In addition there are the more esoteric acceleration mechanisms to which Kurchatov refers only in passing.***

However, it must be mentioned that not all in this acceleration mechanism is yet clear. Under certain conditions acceleration of ions in a longitudinal electric field may also be possible outside the central zone of the discharge due to the presence of space charges. Some types of instability that are peculiar to the column may play an important role in accelerating particles in the plasma. In particular, one type of instability observed experimentally may be of importance for acceleration of electrons. It consists of spontaneous creation of a longitudinal magnetic field in the plasma as a result of spiraling of the plasma column.

If the second contraction is followed by the few more oscillations of the plasma column, the acceleration of the particles may be repeated several times. Experimentally not more than three successive oscillations have been observed. A possible explanation of this is that the plasma may begin to interact with the discharge-tube walls with the result that the wall material begins to evaporate and appreciable amounts of foreign gases appear in the volume.

We considered here some features of the phenomena that accompany the passage of intense pulsed discharges through rarefied gases. The success of further work in this direction will greatly depend on the possibility of creating conditions under which the plasma column will experience multiple oscillations during buildup of the current without coming into contact with the walls. However, there are serious reasons to believe that this cannot be achieved.

On appraising the various approaches to the problem of obtaining intense thermonuclear reactions, we do not deem it possible to completely exclude further attempts to attain this goal by using pulsed discharges. However, other possibilities also must be carefully considered. Especially interesting are those in which the idea of stationary processes may be used.

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*[E. Fermi, *Phys. Rev.* **75**, 1,169 (1949).]

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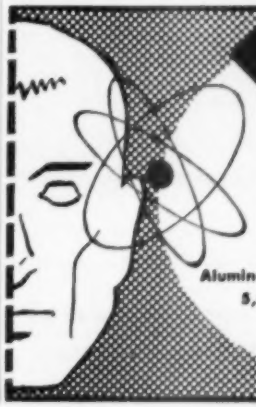

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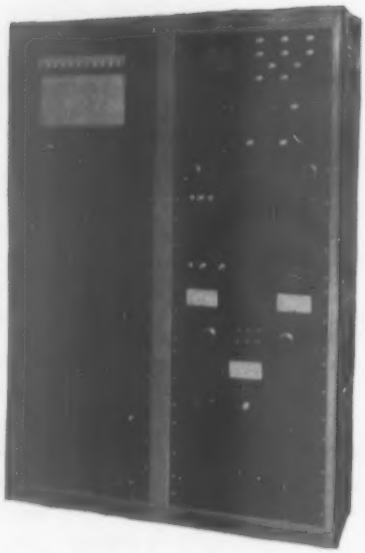

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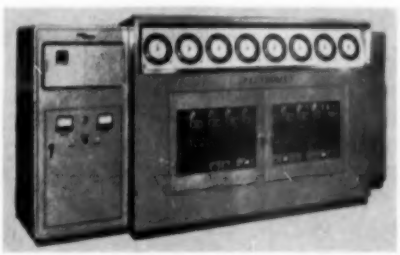

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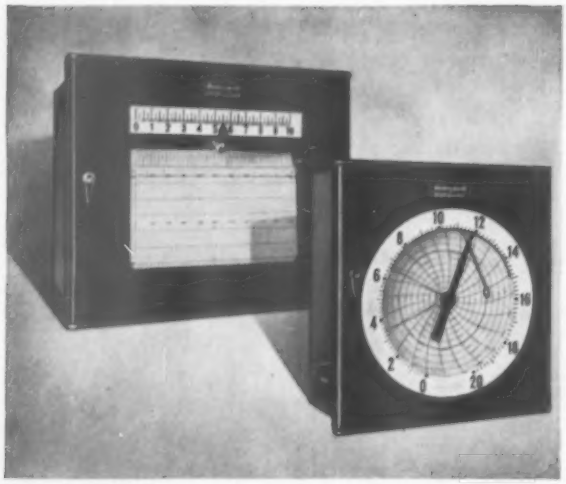

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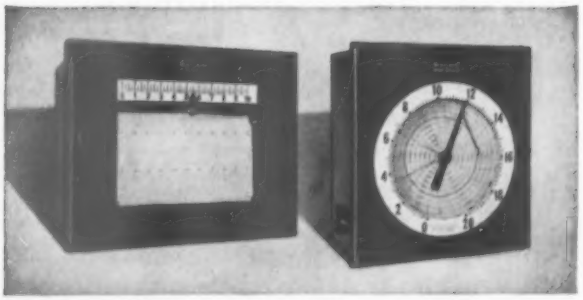

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